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DATA BASE FOR WEATHER RELATED LOADS ON OVERHEAD TRANSMISSION LINES IN ONTARIO

PART 1 - DATA ANALYSIS

Report No 88-220-K

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ABSTRACT

Historical data from 30 Atmospheric Environment Services weather stations in Ontario were utilized to generate information on wind, ice and wind-on-ice loads on overhead transmission lines. This information was then used to provide: 1) tables for annual extreme wind, ice and wind-on-ice loads, 2) annual return period (probability) plots for extreme wind speed, ice thickness and wind-on-ice load and their 95% confidence limits and 3) wind, ice and wind-on-ice loads for several return periods. Also derived from the weather data was information on the correlation between wind and ice values for each weather station. Span factor plots developed from data gathered at Ontario Hydro tower load monitoring sites are presented along with a write-up on the ice modelling procedure used. A user-friendly PC-based computer program was developed to perform all the aforementioned calculations. Part I of this report provides the necessary techniques for the analysis while Part II contains the wind, ice and wind-on-ice load data bases and relevant plots for all the 30 weather stations analysed.

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EXECUTIVE SUMMARY

DATA BASE FOR WEATHER RELATED LOADS ON OVERHEAD TRANSMISSION LINES IN ONTARIO

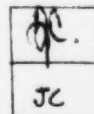
PART 1 - DATA ANALYSIS

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The objective of the project is to assess from historical weather data, wind, ice and wind-on-ice loads on Ontario Hydro's high voltage transmission lines. Historical data collected for a period of up to 33 years at 30 Atmospheric Environment Services weather stations in Ontario were utilized to generate information on wind, ice and wind-on-ice loads on overhead transmission lines. This information was then used to provide the following for each weather station: 1) tables for annual extreme wind, ice and wind-on-ice loads, 2) annual return period (probability) plots for extreme wind speed, ice thickness and wind-on-ice load and their 95% confidence limits and 3) wind, ice and wind-on-ice loads for several return periods. Also derived from the historical weather data was information on the correlation between wind and ice values for each weather station. Span factor plots developed from data gathered at Ontario Hydro tower load monitoring sites are presented along with a write-up on the ice modelling procedure used in the analyses. A user-friendly PC-based computer program was developed to perform all the aforementioned calculations.

Part I of this report provides the necessary techniques to analyse the weather related data for establishing data bases for wind, ice and wind-on-ice loads on overhead transmission lines.

Part II of this report provides the wind, ice and wind-on-ice load data bases for 30 weather stations in Ontario.



job	21-126-331	file	825.151	date	November 17, 1988	report no	88-220-K
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TABLE OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	1
2 WIND, ICE AND WIND-ON-ICE LOADS ON OVERHEAD CONDUCTORS	2
2.1 Wind Load	2
2.2 Equivalent Radial Ice	3
2.3 Ice Load	3
2.4 Wind-on-Ice Load	4
2.5 Available Meteorological data on Wind, Ice and Wind-on-Ice	4
2.5.1 Wind Data	4
2.5.2 Ice and Wind-on-Ice Data	4
2.6 AES Ice Accretion Model and Its Evaluation	
Using Field Data	5
2.6.1 AES Ice Accretion Model	5
2.6.2 Measured Ice Accretion Data	7
2.6.3 Model Evaluation	7
3 ANALYSIS OF WIND AND DERIVED ICE AND WIND-ON-ICE DATA	8
3.1 Analysis of Annual Extreme Wind Data	8
3.2 Analysis of Annual Extreme Ice and Wind-on-Ice Data	9
3.3 Analytical Modelling of Annual Extreme Values	10
3.4 Return Period Estimation	11
3.5 Correlation Frequency of Combined Wind and Ice	11
4 SPAN FACTOR VALUES FOR CALCULATING WIND LOADS ON OVERHEAD CONDUCTORS	12
4.1 Introduction	12
4.2 Ontario Hydro's Wind and Ice Load Monitoring Program	13
4.3 Load Measuring and Data Acquisition System	14
4.4 Calculation of Span Factor Values	14
5 A PC BASED PROGRAM FOR FURTHER DATA ANALYSIS	15
6 CONCLUSIONS	15
7 RECOMMENDATIONS FOR FURTHER WORK	16
APPENDICES:	
I Best-Fit Analyses for Extreme Value Distributions	17
II Kolmogorov-Smirnov Goodness-of-Fit Test	19
III README Instructions for the PC-Based Program	21

Table of Contents cont'd

	<u>Page</u>
REFERENCES	29
DEFINITIONS	30
SYMBOLS	31
TABLES:	
1 Factors for various terrains	32
2 Details of the weather stations considered in the data base	33
3 Results of AES model evaluation for two storms	35
4 Comparison of predicted and measured return period estimates ice accretion thickness (mm) for various return periods	35
5 Annual extreme wind pressure for Toronto International Airport	36
6 Annual extreme ice loads for Toronto International Airport	37
7 Annual extreme wind-on-ice loads for Toronto International Airport	38
8 Conversion factors, K_I , for calculating ice load on any conductor from the ice load on a one-inch diameter conductor	39
9 Conversion factors, K_{WI} , for calculating wind-on-ice load on any conductor from the wind-on-ice load on a one-inch diameter conductor	39
10 Statistical parameters for the probabilistic analysis of the weather data	40
11 Extreme values for selected return periods for Toronto International Airport	41
12 50-year return period weather related data	42
13 Wind speed and ice thickness correlation frequency table for Toronto International Airport	43
14 Details of power lines at tower load measurement sites	44

Table of Contents cont'd

	<u>Page</u>
FIGURES:	
1 Weather stations in Ontario where complete wind, modelled ice and wind-on-ice data are available	45
2 Comparison of predicted and measured annual extreme ice accretion data for London, Ontario (Years 1977-84)	46
3 Comparison of predicted and measured annual extreme ice accretion data for Montreal, Quebec (Years 1975-84)	47
4 Annual Extreme Hourly mean wind speed variation for Toronto International Airport	48
5 Annual extreme radial ice thickness variation for Toronto International Airport	49
6 Annual extreme wind-on-ice load variation for Toronto International Airport	50
7 Analysis of annual extreme wind speed data for Toronto International Airport	51
8 Analysis of annual extreme radial ice thickness for Toronto International Airport	52
9 Analysis of annual extreme wind-on-ice load for Toronto International Airport	53
10 Span factors for Ontario Hydro test spans	54
II.1 Comparison between annual extreme radial ice thickness values and the corresponding Gumble Type I model	55
DISTRIBUTION	last page



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DATA BASE FOR WEATHER RELATED LOADS ON OVERHEAD TRANSMISSION LINES IN ONTARIO

PART 1 - DATA ANALYSIS

1 INTRODUCTION:

In designing transmission lines, it is necessary to consider a large number of random and interacting loads such as wind load, ice load, wind-on-ice load etc. Design wind and ice loads can be established either from actual measurements or from available historical weather data. Eventhough it would be desirable to utilize actual measured data, it is prohibitively expensive and time consuming. If there is sufficient weather data available then the wind, ice and wind-on-ice loads can be calculated using appropriate mathematical relationships. There is adequate measured historical data available to calculate wind loads on overhead lines, but the available information on ice and wind-on-ice is inadequate to use in load calculations.

The lack of measured historical data on ice and wind-on-ice could be overcome in two ways:

- .establish a network of stations to gather data on ice and wind-on-ice over an extended period of time sufficient for statistical analysis.
- .utilize the already available weather data such as wind speed and direction, temperature, precipitation, etc. to predict the ice and wind-on-ice loading by way of appropriate modelling.

The first method of gathering field data on ice and wind-on-ice should be the long range objective of any data base program. But in the mean time the modelling route to estimate ice and wind-on-ice loads should be actively pursued because at least 10 to 15 years is required before the data gathered in a field program could be used in design calculations. The data base discussed in this report was established as follows:

- .wind loads were assessed from historical weather data,
- .ice and wind-on-ice loads were calculated using ice accretion models and historical weather data.

The ice accretion model used in this project is a modified version of the one developed by Atmospheric Environment Services (AES) of Environment Canada/1,2/ which was recently verified by using a limited amount of field data gathered in Ontario and Quebec/3/.

Based on the approach described above, a data base was developed to provide the following weather related information for 30 AES weather stations with reference to overhead transmission line design:

- . tables and computer-based information of annual extreme wind, ice and wind-on-ice loads for each weather station.
- . return period (probability) plots for annual extreme wind speed, ice thickness and wind-on-ice loads for each weather station along with their 95% confidence bounds.
- . wind, ice and wind-on-ice loads for several return periods for each of the weather stations.
- . tables for wind and ice correlation frequencies for each of the weather stations.

Also discussed are the span factor plots developed from data gathered at Ontario Hydro tower load monitoring stations and a write-up on the verification of the ice accretion model. A PC-based, user-friendly, interactive computer program was developed to analyse the situations that are not included in the standard tables and plots.

It should be noted here that the direct loads on towers due to wind, ice and wind-on-ice are not discussed in this report.

2 WIND, ICE AND WIND-ON-ICE LOADS ON OVERHEAD CONDUCTOR

In this section the various relationships used for calculating wind, ice and wind-on-ice loads will be discussed in some detail. The relationships used in this report are close to the ones used in design calculations in Ontario Hydro.

2.1 Wind Load

The transverse wind load on a bare conductor is:

$$P_W = C_1 S V^2 D L / 12 \quad (1)$$

where P_W - wind load (lb)
 C_1 - constant (0.003)
 S - span factor (1.0)
 D - conductor diameter (in)
 L - span length (ft)
 V - wind speed at the conductor height (mph)

The value of span factor is a function of conductor drag, span length and terrain characteristics and can be obtained from field observations of wind loading on overhead lines/4/. The mean wind speed V at the appropriate conductor height is assessed by the following relationship:

$$V = \left(\frac{H}{H_n} \right)^\alpha V_n \quad (2)$$

where V_n = mean wind speed at height H_n (mph)
 H_n = height at which wind speed was recorded (ft)
 V = mean wind speed at the mean conductor height (mph)
 H = mean conductor height (conductor attachment point - 2/3 sag)
 α = power law exponent representative of terrain,
 (see Table 1 for some typical values)

2.2 Equivalent Radial Ice

The information used in this study for calculating equivalent radial ice thickness was derived from AES (Atmospheric Environment Services) archives using an updated Chaine ice accretion model /1/. The ice accretion value obtained from the AES model is defined in two parts; ice accretion on horizontal surface (A_h) and ice accretion on vertical surface (A_v). From the horizontal and vertical ice accretion values the equivalent radial ice on a conductor is calculated from:

$$t = [kr/2 (A_h^2 + A_v^2)^{1/2} + r^2]^{1/2} - r \quad (3)$$

where k = a correction factor depending on the conductor size and air temperature, $k = 1 / (0.1858 + 0.156 \cdot 2 \cdot r)$ at 0°C
 A_h = ice accumulation on vertical surface (in)
 A_v = ice accumulation on horizontal surface (in)
 r = radius of conductor (in)
 t = equivalent radial ice thickness (in)

2.3 Ice Load

The ice load on a conductor is given by

$$P_I = \frac{w \pi}{576} [(D + 2t)^2 - D^2] L \quad (4)$$

where w = density of ice (lb/ft^3), assumed to be 57 lb/ft^3
 D = conductor diameter (in)
 t = equivalent radial ice thickness (in)
 L = span length (ft)
 P_I = ice load (lb)

The procedure to derive appropriate ice accretion value is described in Section 2.5.

2.4 Wind-on-Ice Load

The wind and ice values used in calculating the transverse load on an ice-covered conductor are different than those used in calculating the loads due to wind only and ice only. The procedures to calculate the appropriate wind-on-ice values are described in detail in section 2.5.2. The combined wind and ice information used in this study was derived from AES archives by using the updated Chaîne ice accretion model/1/.

Knowing the equivalent radial ice thickness t_{WI} and the maximum wind speed associated with the ice storm the wind-on-ice load can be calculated by

$$P_{WI} = C_1 S V^2 \left(\frac{D+2t_{WI}}{12} \right) L \quad (5)$$

where C_1 = constant (= 0.003)
 S = span factor (=1.0)
 V = maximum mean wind speed during an ice storm (mph)
 D = conductor diameter (in)
 t_{WI} = equivalent radial ice thickness (in)
 L = span length (ft)
 P_{WI} = transverse load due to wind-on-ice

2.5 Available Meteorological Data on Wind, Ice and Wind-on-Ice

This section describes the sources of data and how the data were used in the calculation of wind, ice and wind-on-ice loads on overhead lines.

The information on wind, ice and wind-on-ice used in this study was retrieved from AES archives for 30 weather stations in Ontario (Figure 1) by using a special computer program/1/

2.5.1 Wind Data - The annual extreme wind speed values were derived from hourly mean wind speed measurements. The information on the anemometers heights and a description of surrounding terrain, Table 2, were used to extrapolate the wind speed to different conductor heights, using Eq.2.

2.5.2 Ice and Wind-on-Ice Data - Information on annual extreme ice and wind-on-ice for all the weather stations was derived from weather data such as wind speed, temperature, precipitation etc. /1/. Using the ice accretion model described in detail in Section 2.6, ice accretion values on horizontal and vertical surfaces were calculated for each year to establish the corresponding annual extreme radial ice (Eq.3).

Each set of annual extreme wind-on-ice data consists of ice accretion on horizontal and vertical surfaces during an ice storm and the maximum wind speed measured during the storm, and also for that part of the 24-hour period following the storm during which the temperature remains below freezing. The equivalent radial ice thickness calculated using Eq.3 was used along with the maximum wind speed to calculate the maximum wind-on-ice load from Eq.5.

The basis of selecting an ice storm for calculation of annual extreme ice is different from that of selecting an ice storm to provide the annual extreme wind-on-ice data. The ice storm yielding the annual extreme ice need not also necessarily produce the annual extreme wind-on-ice event. In choosing the ice storms for calculating annual extreme ice and annual extreme wind-on-ice data the following steps were used:

Assume that there are n ice storms during a given year.

1. For each of the n storms calculate:
 - (a) the maximum equivalent radial ice accretion, and
 - (b) the maximum wind-on-ice transverse load (for a one-inch diameter reference conductor).
2. From the calculated values of ice accretion (step 1-a) and wind-on-ice load (step 1-b) two ice storms are selected:
 - (a) one providing the maximum ice accretion, and
 - (b) the other the maximum wind-on-ice transverse load.
3. The ice storm providing the maximum equivalent radial ice represents the annual extreme ice data from which the annual extreme load due to ice only is calculated. The annual ice storm providing the maximum wind-on-ice transverse load represents the annual extreme wind-on-ice data from which the annual extreme wind-on-ice transverse load is calculated.

Using the wind, ice and wind-on-ice data, the following loads on an overhead conductor can be calculated:

- (a) maximum transverse load (due to wind only) from the annual extreme wind data,
- (b) maximum vertical load from the annual extreme ice data, and
- (c) maximum transverse load (due to wind-on-ice) from annual extreme wind-on-ice data.

2.6 AES Ice Accretion Model and Its Evaluation Using Field Data

AES ice accretion model used in this report was evaluated using limited field data available on ice accretion. Data collected by Ontario Hydro at one of its tower load monitoring sites and data gathered by Hydro Quebec was used in the model evaluation.

2.6.1 AES Ice Accretion Model - The AES ice accretion model was initially implemented to provide estimates of ice and wind-on-ice loadings on transmission lines using hourly climatological data recorded at Canadian first order stations. The model combines estimates of horizontal ice accretion, A_h , derived from the depth of measured freezing precipitation, with vertical ice accretion, A_v , to obtain the equivalent radial ice thickness on conductor, t , from Eq.3. A_v in Eq.3 is calculated using the relationships:

$$A_v = \sum_{i=1}^N A_{v,i} \quad (6-a)$$

and

$$A_{v,i} = (0.0633 V) (1.24 g^{0.88}) \quad (6-b)$$

where $A_{v,i}$ - ice accumulation on a vertical surface during the i -th hour of an ice storm
 V - wind speed (mph)
 g - precipitation intensity (in/hr)⁴
 N - number of hours in the icing event

The correction factor k , see Eq.3, was obtained from comparisons between the model and experimental ice accretions amounts/5/. The model assumes a fixed value for k corresponding to a one inch diameter conductor. Other assumptions contained in the model are:

- collection efficiency of 1.0
- ice density same as liquid water
- ice accretes under dry growth regime
- wind always perpendicular to conductor axis

Although k is sensitive to changing cylinder diameter, this time-dependent feedback was not incorporated in the model. In the latest implementation/1/, hourly changes in the type and intensity of freezing precipitation were taken into account following an intensity-weighting scheme developed by Ontario Hydro/6/. This scheme also partitions out any solid precipitation contribution to the total precipitation measured during an icing event.

The model requires hourly wind speed, air temperature and precipitation information (type and intensity) along with 6-hourly total precipitation amounts. Individual events are assumed to begin with the first report of freezing precipitation and end 24 hours after the last report or when the air temperature rises above 1°C if this occurs sooner.

To date, the AES freezing precipitation model has been subjected to only limited verification as part of a storm-by-storm ice accretion model evaluation methodology/1/. This verification has shown the AES model to perform very well for two freezing precipitation storms in southern Ontario (Table 3). Measured data for the two events were obtained from transmission line load monitoring stations/4/.

While the collective results of individual storm-based comparisons are important for determining model performance characteristics such as bias and noise, from an engineering point of view, evaluation may yield more useful information if carried out in the context of design application. That is, a model's ability to predict annual extreme events and produce realistic design ice accretion values.

The obstacle to this *design-oriented* approach to model evaluation is the lack of available long periods of continuously observed ice accretion data. The best available Canadian sources were 8 years of data (1977-1984) from Ontario Hydro's transmission line load monitoring station near London, Ontario, and 10

years of data (1975-1984) from Hydro-Quebec ice accretion measurement site at Montreal International Airport. It is recognized that these data may be somewhat limited to provide any sort of reliable extreme value analysis for the sites in questions. However, they are still useful for providing an initial evaluation of the model.

2.6.2 Measured Ice Accretion Data - Measured ice accretion data from the Montreal and London sites were used to obtain annual extremes for comparison with the AES model data. The measurement programs and data characteristics at each site are briefly described below:

London Measurement Site: Since 1976, Ontario Hydro has maintained a network of test sites in southern Ontario/4/ to monitor wind and ice loads on 230 kV and 500kV overhead transmission lines. One of these test sites is located on the outskirts of London, Ontario, approximately 10 miles from London Airport weather station. The details of the instrumentation package used in the test site and other related information are given in /4/. The equivalent radial ice accretion on the conductor is calculated from the increase in vertical load during an ice storm. Data gathered during the years 1977 to 1984 were processed to obtain annual extreme equivalent radial ice accretion values.

Montreal Measurement Site: Hydro-Quebec has maintained a wide network of measurements sites in Quebec to monitor ice accretion, one of which is located at Montreal International Airport. Ice accretion thickness measurements are carried out using a passive ice meter with 0.394 in diameter rods and 1 in diameter cylinders oriented north, south, east and west. During icing events manual measurements are made of the ice thickness on the various rods, cylinders and surfaces which make up the meter. Ice thickness data from the Montreal site were supplied by Hydro-Quebec/7/.

Equivalent radial ice values were not available from the Montreal passive ice meter because Hydro-Quebec archives the maximum ice thickness values on each of the various ice meter components. Therefore, the maximum ice thickness value on the 1 in diameter cylinder for each storm was used to select annual maxima for the model comparison. It is realized that these data differ from those obtained at the London site; under the same icing conditions, the ice meter value is likely to be greater than that obtained from integrating the ice load over 418 meters of conductor. However, it was felt that the Montreal data could still provide valuable insights into the performance of the AES model.

2.6.3 Model Evaluation - The AES model was run for the London and Montreal Airport first order climate stations and annual maximum values of radial ice thickness were obtained for the 1977-84 and 1975-84 periods respectively. The predicted and measured annual extreme ice thickness values were fitted to the Gumble Type I distribution using the method of moments (Figures 2 and 3). The comparison of the predicted and measured ice accretion values for the 2, 5 and 10 year return periods is given in Table 4.

The Montreal results show the model to perform very well at predicting the annual maximum ice accretion thickness as opposed to the equivalent radial ice thickness in the London case: the London results show the model to

consistently overpredict the annual maximum equivalent radial ice values. These two sets of results suggest that AES model is over predicting equivalent radial ice values. Possible explanations for this over prediction are discussed in /3/.

3 ANALYSIS OF WIND AND DERIVED ICE AND WIND-ON-ICE DATA

The wind, ice and wind-on-ice data derived in the previous section from the AES weather records were analysed to obtain the following information with reference to transmission line design and maintenance:

- a) extreme wind, ice, and wind-on-ice loads on conductors
- b) values of wind, ice, wind-on-ice and the corresponding loads for various return periods, and
- c) correlation frequency for combined wind and ice events

In this section the analyses method are briefly discussed along with some typical results.

3.1 Analysis of Annual Extreme Wind Data

Annual extreme hourly mean wind speed data for 30 Ontario weather stations were obtained from AES records. The anemometer heights at all the 30 weather stations were not the same and at some stations the anemometer height had changed a few times since they were installed (Table 2). Therefore, in order to provide coherent information for all the stations, it was decided to translate the wind speeds to a standard height of 33 ft, using the power-law relationship of Eq.2. Values of the terrain factors (see Eq.2) were obtained by analysing the nature of the terrain around each station and are given in Table 2. In cases where there were no information available about anemometer height and/or terrain type, it was assumed that the terrain was flat ($\alpha = 0.16$) and the anemometer was located at 33 ft height. Figure 4 shows the variation of annual extreme wind speeds for the Toronto International Airport station at the standard height of 33 ft.

Using Eq.1 the wind induced transverse pressure on a one-inch conductor is calculated for various annual extreme wind speeds. Note that although in the present calculations the value of the span factor, S , was assumed to be unity, there is evidence that in real situations the value of S is a function of terrain, span length, etc. and is significantly smaller than unity. This point will be discussed in more detail in Section 4. It should be noted that in all the wind load calculations, the wind direction is assumed to be normal to the conductor axis.

In Part II of this report, tables for the annual extreme mean wind and gust speeds and the corresponding pressures on conductors at 33 and 132 ft heights are provided for all the stations. Table 5 shows one such table for the Toronto International Airport weather station. The gust speeds were obtained using the equation:

$$V_g = 1.29 V + 5.8 \quad (7)$$

where V_g and V are the gust and mean wind speeds in mph, respectively.

3.2 Analysis of Annual Extreme Ice and Wind-on-Ice Data

The annual extreme radial ice thicknesses were calculated from the AES ice model using horizontal and vertical ice accretion measurements (Eq.3). The variation of extreme equivalent radial ice thickness for the Toronto International Airport station during a 31 year period is shown in Fig.5. The ice load per unit span length(L) was calculated from Eq.4. The annual extreme radial ice values and the corresponding ice loads for the 30 Ontario weather stations were calculated and are presented in Part II of this report. The values of annual extreme ice loads at the Toronto International Airport station are presented in Table 6.

Wind speed and ice thickness values used in extreme wind-on-ice load analysis were obtained by the method described in section 2.5. Using Eq.5 the wind-on-ice loads on a one-inch conductor were calculated for all the Ontario stations and are presented in Part II of this report. The annual variation of the extreme wind-on-ice loads at the Toronto International Airport station is shown in Fig.6. Table 7 shows the extreme radial ice and wind speed values and the resulting wind-on-ice pressure for the same station. The loads calculated in Table 7 are for a one-inch conductor.

The AES ice accretion model uses a one-inch conductor to calculate ice and wind-on-ice loads. However in many real applications the conductor size will be very different than the one-inch conductor used in the model. Therefore approximate corrections would be applied to account for different conductor size. In this section correction factors are developed for a variety of conductor sizes.

The relationship for calculating ice load, Eq.4, can be rewritten as a function of ice load on a one-inch conductor as shown below

$$P_I = K_I P_{I(1)} \quad (7)$$

$$\begin{aligned} \text{where } K_I &= (D+t)/(1+t) \\ P_{I(1)} &= \text{ice load on a one-inch conductor.} \end{aligned}$$

Similarly the relationship used to calculate wind-on-ice load, Eq.5, can be rewritten as

$$P_{WI} = K_{WI} P_{WI(1)} \quad (8)$$

$$\begin{aligned} \text{where } K_{WI} &= (D+2t)/(1+2t) \\ P_{WI(1)} &= \text{wind-on-ice load on a one-inch conductor.} \end{aligned}$$

Values of K_I and K_{WI} for various conductor sizes and ice thicknesses are given in Tables 8 and 9 respectively. For example, for a case when the radial ice thickness on a one inch conductor is 0.5 inches, the load on a 1.5 inch conductor can be estimated by multiplying the ice and wind-on-ice loads on a one inch conductor by 1.33 and 1.25, respectively.

3.3 Analytical Modelling of Annual Extreme Values

In this section, the analysis of annual extreme wind, ice and wind-on-ice data, by means of extreme value techniques, is discussed. Previous analyses of annual extreme wind speeds/8/ have shown that the cumulative probability of extreme wind speeds closely corresponds to a Gumble Type I distribution of the form:

$$P(V) = \exp (- \exp [(B-V)/C]). \quad (9)$$

In the above relationship V is the annual extreme wind speed and B and C are the location and scale parameters for the distribution. Equation 9 can be rewritten as

$$RV = - \ln (- \ln [P(V)]). \quad (10)$$

where RV , called the reduced variate, is defined as

$$RV = (V-B)/C . \quad (11)$$

Note that in Eq.11, there is a linear relationship between reduced variate, RV , and the extreme wind speed, V . Therefore, using the measured annual extreme wind speed data, the coefficients B and C for the Gumble Type I extreme distribution, Eq.9, can be estimated by a bestfit technique. A brief overview of the more widely used bestfit techniques, including the one used in this report, is given in Appendix I.

The extreme value analysis technique described above were used to analyse the wind, ice and wind-on-ice data from all the AES weather stations studied in this report. A typical set of extreme value plots along with 95% confidence bounds for the Toronto International Airport station are shown in Figs.7, 8 and 9. Similar plots for all the weather stations (Fig.1) are given in Part II of the report. The confidence bounds were calculated using the procedure described in /9/. In general the Gumble Type I extreme value distribution represented fairly well the wind, ice and wind-on-ice data. The extent to which the model represents the actual data is evaluated by the classical Kolmogorov-Smirnov goodness-of-fit technique which is described in detail in Appendix II. The goodness-of-fit indexes for all the extreme value fits were evaluated and are listed in Table 10. The average, minimum and maximum values of goodness-of-fit indexes for all the 30 AES stations are also listed in Table 10. It could be seen from this table that in general the Gumble Type I distribution represents fairly closely the annual extreme wind, ice and wind-on-ice data.

3.4 - Return Period Estimation

Gumble Type I plots such as shown in Figures 7, 8 and 9 were used for estimating the amount of wind, ice and wind-on-ice for any return period. This is done either by graphically extrapolating the extreme plots or by analytical means as explained below.

The values of wind speed, ice thickness or wind-on-ice load for a given return period can be estimated using the corresponding location and scale parameters, B and C, and the relationship

$$\frac{X-B}{C} = - \ln [- \ln (\frac{RP-1}{RP})] \quad (12)$$

where RP = Return period

X = value of wind speed, ice thickness or wind-on-ice load

Table 10 provides the values of B and C for wind, ice and wind-on-ice data for all the stations in the data base. The wind or ice load for a given return period is obtained by first estimating the value of corresponding wind speed or ice thickness from Eq.12 and then calculating the load from Eqs.1 or 4. Table 11 shows the predicted extreme values for wind speed, wind pressure, radial ice accumulation, ice load, wind-on-ice pressure, gust speed, gust pressure and gust-on-ice pressure for 10, 20, 40, 50, 60, 80, 100, 200 and 500 years return periods. The upper and lower 95% confidence limits are also included in the table. Values of the 50-year return period wind speed, wind pressure, gust speed, gust pressure, radial ice thickness, ice load and wind-on-ice load for all the stations are listed in Table 12. Also included in this table are the mean, maximum, minimum and coefficient of variations for the aforementioned 50-year return values.

3.5 Correlation Frequency of Combined Wind and Ice

In the previous sections of this report the probabilities of annual extreme wind-on-ice data were studied and Gumble Type I distributions were developed to predict the wind-on-ice load values for various return period values. In this section, however, the wind-on-ice data (not just the annual extreme values) for each of the weather stations will be analysed to calculate the number of times that the various combination of wind and ice will occur. Each value, representing the number of times combined wind and ice can occur, is called the correlation frequency. The wind data used in the calculations correspond to a standard height of 33 ft and the ice values represent the radial accretion on a one-inch conductor. A computer program was developed to construct correlation frequency values such as that shown for the Toronto International Airport in Table 13. The program makes use of ice storm information developed from AES weather data to calculate the correlation frequencies. For each weather station the program analyses all the ice storm, one at a time, to calculate the number of times any combination of wind and ice occurred. In Part II of this report a separate correlation frequency table is given for each of the AES weather stations studied.

Each correlation frequency table has two axes, wind and ice, each of which is divided into several divisions to form various 'cells'. A typical cell represents a wind speed range of 5 mph and a radial ice of 0.0125 inch. Each cell contains three correlation frequency values, which are defined as follows:

- a) The upper value represents the number of times the combined wind and ice occurrences were within the ranges specified for the cell.
- b) The middle value represents the number of times the wind speed values were within the range specified for the cell and the ice values ranged from 0 to the maximum value specified for the cell. This value is given as a percentage of the total number of combined wind and ice events in the data base. It is in effect a partial cumulative correlation frequency of combined wind and ice events.
- c) The lower value represents the number of times both wind speed and ice accretion values ranged from 0 to the maximum value specified for the cell. This value is presented as a percentage of the total number of combined wind and ice events in the data base.

For example the upper, middle and the lower values in the shaded cell in Table 13 can be explained as follows.

- . The upper number means that out of the 213 ice storms recorded at the Toronto International Airport for a period of 31 years, 7 produced combined wind and ice values that ranged from 20 to 25 mph and 0.025 to 0.05 inches respectively.
- . The middle number means that 10.8% of all the observed storms had combined wind and ice values ranging from 20 to 25 mph and 0 to 0.05 inches respectively.
- . The lower number means that 46.5% of all the observed storms had combined wind and ice values ranging from 0 to 25 mph and 0 to 0.05 inches respectively.

4 SPAN FACTOR VALUES FOR CALCULATING WIND LOADS ON OVERHEAD CONDUCTORS

4.1 Introduction

To calculate the transverse wind load for a tower design, a designer should have data on wind velocity and an equation for calculating the wind pressure on conductors. The data from local weather records can be used to determine an appropriate wind velocity. Assuming that the wind acts uniformly over the whole span, the corresponding wind load, P_w , can be calculated by the following relation:

$$P_W = p_W L D \quad (13)$$

where p_W = wind pressure on conductor = $(1/2) \rho V^2 C_{DC}$
 D = conductor diameter
 L = conductor span
 ρ = air density
 V = mean wind speed normal to the conductor axis, and
 C_{DC} = conductor drag coefficient

The use of an appropriate value for the conductor drag coefficient is critical in calculating realistic wind loads. Based on data from wind tunnel studies a value of unity is commonly recommended in design guides which, as seen in/4/, could lead to excessive loads at high wind speeds.

The actual transverse load that a conductor would be subject to (P_M) could be measured using an instrument package described in the next section. Since the wind velocity is not uniform over the span as it is assumed to be in calculating the transverse load, the measured wind load will be different than the calculated load (P_C) by a factor, say S . This factor is called the span factor and can be determined by:

$$S = \frac{P_M}{P_C} \quad (14)$$

In order to establish a relation between the wind velocity component normal to the conductor and S , many sets of field data covering a wide range of conditions are required. The instrumentation package and the data analysis for establishing S for different span lengths and conductor sizes will be briefly discussed below.

4.2 Ontario Hydro's Wind and Ice Load Monitoring Program

Recognizing the need for a better understanding of the effects of weather related loads on transmission and distribution lines, Ontario Hydro has established a network of field test sites to monitor wind and ice loads on overhead power lines. As part of this long term program a complete instrumentation package has been developed to measure wind and ice loads on conductors, insulator swing angles, dynamic loads due to conductor galloping, wind speed and direction, air temperature and precipitation.

Since 1975 the measuring system has been in operation at several locations in Southern Ontario (Table 14). From these monitoring stations a significant amount of information has been gathered on the behaviour of overhead transmission lines under wind and ice loading. The information from these measurements is contributing to a data base from which improved design standards may evolve and on which new probabilistic design methods may be based.

4.3 Load Measuring and Data Acquisition System

The conductor load measuring system consists of a commercial load cell and two rotary transducers attached through a universal joint to the tower arm in series with the insulator string. The insulator swing angles in two orthogonal directions are measured by the two rotary transducers mounted on the load cell frame. From the measured insulator string load and swing angles, the vertical, longitudinal and transverse components of conductor load can be calculated. At one of the stations strain gauges and linear displacement transducers are also used to measure the response of tower legs and foundation movements respectively. The instruments are effectively protected against snow, ice and rain. A propeller-type anemometer located at the top of the tower is used to measure wind speed and direction. The Orangeville site also has an ice-free anemometer and a precipitation gauge.

The data acquisition system consists of a microprocessor based data analyzer and a digital tape recorder. It is capable of providing statistical information on conductor loads and wind, and switching to a faster recording mode for collecting data on ice storms and conductor galloping. The details of the package is given in/4/.

4.4 Calculation of Span Factor Values

The span factors defined above are calculated using Eqs.13 and 14 as explained below:

- . choose any set of measured wind speed (approximately normal to line axis) and the corresponding measured transverse load (P_m)
- . calculate the transverse load (P_c) corresponding to the measured wind speed (step 1) component normal to line axis
- . calculate the ratio between P_m and P_c (i.e., S)
- . repeat the above steps for many sets of measured wind speed and measured transverse loads
- . plot the values of S calculated above against the wind speed component normal to line axis

The span factor-wind speed plots are done for the tower load monitoring sites located near London, Orangeville, Brantford and Nanticoke. The maximum wind speeds observed at these sites ranged from 60 mph to 70 mph. The span lengths at the measuring sites ranged from 710 ft to 1510 ft while the conductor diameters ranged anywhere from 0.87 inch to 1.6 inch. The terrain at the sites varied from flat farmland to farmland with dense bushes bordered on side by houses.

The span factor-wind speed plots for the four sites are shown in Figure 10. In general the span factor should be a function of wind speed, span length, conductor size, terrain .etc. From Fig.10, however, it is seen that the effect of all these parameters except the wind speed is not significant enough

to influence the trend of span factor values. As seen from the plots the span factor, in other words the ratio between the measured and the calculated loads, seem to decrease significantly with wind speed.

5 A PC-BASED PROGRAM FOR FURTHER DATA ANALYSIS

The data presented in the previous section provide information on annual extreme wind, ice and wind-on-ice values and related loads for the 30 AES weather stations considered in this report. These information are however limited to the specific situations, such as conductor height, conductor size, span length, etc., for which the calculations were performed. In order to make the extreme value analyses discussed in this report easily applicable to any other situation, a PC-based software package was developed. The package consists of programs WINDICE1 and WINDICE2 and the data files for the 30 AES weather stations.

WINDICE1 is an interactive program which calculates the information in Tables 5 to 7 corresponding to any specified height and allows the use of different values for C_1 in Eqs.1 and 5. It also provides tables such as Table 11 for any specified return periods. Correlation frequency values, similar to the ones given in Table 13, can also be calculated for any specified intervals of equivalent radial ice and wind speed.

WINDICE2 is similar to WINDICE1 except that it requires conductor diameter and span length information and calculates the actual loads on the span rather than pressures or loads per unit length calculated by WINDICE1. The README file for the package is presented in appendix III.

6 CONCLUSIONS

The analysis of the weather data collected at 30 AES weather stations has resulted in a comprehensive data base for assessing the annual extreme wind, ice and wind-on-ice loads on overhead transmission lines. This province-wide data base will be useful in the design of transmission lines either by deterministic or probabilistic methods.

It was also established that a Gumble type I distribution is generally suitable for describing the probability distribution of extreme wind speed, radial ice and wind-on-ice loads.

The extreme value analysis performed on the weather data helps to predict the weather related loads corresponding to various return periods.

The limited verification of the AES combined wind-on-ice accretion model used in this study provides a certain confidence in the predicted ice and wind-on-ice values.

The span factor values derived from the Ontario Hydro study illustrates the need for reassessing the currently applied factors in the design calculations.

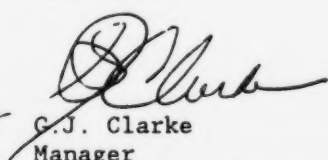
The PC-based computer programs developed as part of this project would be useful since they can be utilized to calculate the weather related loads to any situations that are not considered in this report.

7 RECOMMENDATION FOR FURTHER WORK

The following are the recommendations for further work related to wind, ice and wind-on-ice data bases:

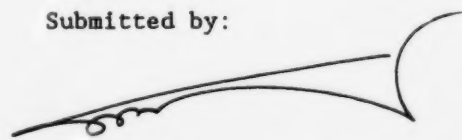
- . Using the data bases developed in this report attempt to formulate relatively smaller areas for specifying design loads compared to the existing two areas for the province of Ontario.
- . Establish more number of tower load monitoring stations to study the effect of different terrains, span lengths etc, on span factor.
- . Include the effect of wind direction on wind loads (some basic work has already been done/10/).
- . Assess the direct wind, ice and wind-on-ice loads on transmission line towers (the weather related loads in this report are due to conductors only).

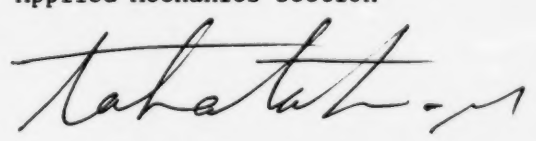
Approved by:


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cc

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& Structures
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M. Tabatabai
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APPENDIX I

BESTFIT ANALYSIS FOR EXTREME VALUE DISTRIBUTIONS

In order to describe a variation by a Gumble type I extreme value distribution, it is necessary to determine the values of the constants B and C in Eq.9. The following is a brief description of some of the more popular methods available for obtaining these constants.

Using Eqs. 10 and 11 (Section 3.3), it is seen that a variable V, annual extreme wind speed for example, can be written in the form of:

$$V = B + C \cdot RV = B + C (-\ln [-\ln P(V)]) \quad (I.1)$$

where P(V) is the cumulative probability of occurrence of V. Note that Eq.I.1 is a linear equation and having a set of values for V, and their corresponding P's, B and C can be determined. In the present case V is deduced from the AES weather data and the value of P is calculated using the relationship:

$$P(V) = i/(n+1) \quad (I.2)$$

where n is the total number of available observations and i is an integer from 1 to n corresponding to the rank of V in ascending order. Note that for estimating P(V), other relationships such as $P(V) = (2i - 1)/2n$ have also been proposed. Having V and P(V) values, parameters B and C can be estimated, with varying degree of accuracy from Eq.I.1. A comprehensive discussion about the available procedures and their corresponding efficiency can be found in Mann/11/. The following is a brief description of some of the more popular methods.

The Least Square Method - This is by far the most widely used method of linear regression. Note that the use of a least square method implies that the probability density function of the error associated with the regression model is known to have a Normal distribution (which in the present case is not true!).

The Modified Moment Method - There are two types of bestfit estimation methods which are known as the moment methods. One is the so-called modified moment method in which B and C are calculated from relationships:

$$C = \frac{\sigma_V}{\sigma_{RV}} \quad (I.3)$$

and

$$B = V_{avg} - RV_{avg} \sigma_V / \sigma_{RV} \quad (I.4)$$

In Eqs.I.3 and I.4 the mean and standard deviations, σ , are calculated from:

$$V_{avg} = \frac{\sum_{i=1}^n [V(i)]}{n} \quad (I.5)$$

$$RV_{avg} = \frac{\sum_{i=1}^n [RV(i)]}{n} \quad (I.6)$$

$$\sigma_V = \left(\frac{\sum_{i=1}^n V(i)^2 - n V_{avg}^2}{(n-1)} \right)^{1/2} \quad (I.7)$$

$$\sigma_{RV} = \left(\frac{\sum_{i=1}^n RV(i)^2 - n RV_{avg}^2}{n} \right)^{1/2} \quad (I.8)$$

The second moment method is a simplified form of the above relationships, using the fact that RV_{avg} and σ_{RV} are asymptotically equal to Euler's constant of

$$0.5772 \text{ and } \frac{\pi}{\sqrt{6}}.$$

Substituting these values in Eqs.I.3 and I.4, we get:

$$C = \frac{\sqrt{6}}{\pi} \sigma_V \quad (I.9)$$

and

$$B = V_{avg} - .5772 \frac{\sqrt{6}}{\pi} \sigma_V \quad (I.10)$$

The Maximum Likelihood Method - If the pdf of the errors associated with the estimated bestfit does not have a normal distribution, a more robust regression procedure such as the maximum likelihood method should be used. The maximum likelihood method is an iterative procedure, which provides the most probable bestfit coefficients for the observed values.

Mann/11/ performed a comparison of the errors associated with the various bestfit estimation of an extreme value distribution. The maximum likelihood method was found to provide the most accurate results. For example, the expected loss in the estimate of B from a sample size of 20 was found to be 0.09 from the modified moment method, 0.05 from the simplified moment method, and 0.03 from the maximum likelihood method. (Loss was defined as the expected error divided by B^2).

APPENDIX II

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST

The Kolmogorov-Smirnov goodness-of-fit test is a suitable goodness-of-fit test for cases when the underlying distribution of the data is known (or perceived to be known). This is the case in the present situation where the probability functions are assumed to have the form of a Gumble type I distribution.

The Kolmogorov-Smirnov goodness-of-fit test involves calculating the maximum difference between the actual (measured) and predicted (model) cumulative probabilities, i.e.:

$$\Delta = \text{Max} (\text{ABS}[P(V)_{\text{actual}} - P(V)_{\text{bestfit}}]) \quad (\text{II.1})$$

This difference is then used to estimate the goodness-of-fit index, GOF, using the following relationships:

$$\text{KOL} = \sqrt{n} \Delta \quad (\text{II.2})$$

and

$$\text{GOF} = 100 (1 - [\sqrt{2}\pi \exp(0.125\pi^2/\text{KOL}^2)] / \text{KOL}) \quad (\text{II.3})$$

Note that a GOF of 90% indicates that a hypothesis stating "*the underlying trend of the data has a Gumble type I distribution*" can be rejected with a confidence level of 10%, i.e. there are good chances that the distribution does follow the Gumble type I distribution. There are no set criterion by which the Kolmogorov-Smirnov test can categorically accept or reject a proposed model for a distribution. A certain degree of intuition based on previous experience is therefore required. Also note that the test can produce quit discouraging results even when only one of the measured points has a large deviation from the proposed probability distribution. Figure II.1 shows the cumulative density distribution of the annual extreme ice thickness values at the Toronto International Airport weather station and the Gumble type I distribution obtained using the maximum likelihood bestfit procedure. Note that this figure is more suitable for a visual inspection of the goodness-of-fit than Figure 8 because in the latter the differences at large reduced-variates are greatly exaggerated by the double exponential scale of the ordinate. Also note that Eqs.II.2 and II.3 are approximate relationships and are suitable for cases when the number of points used in the bestfit/goodness-of-fit analysis are large, say larger than 20. The usefulness of these relationships decrease when the number of points used in the analysis decrease. Since the values recorded in figures such as Fig.8 were obtained using Eqs.II.2 and II.3, the following procedure can be used to obtain more accurate GOF values for cases when there are less than 20 years of data in the data base:

- Use the value of GOF, in percentages, given in figures such as Fig.8 to calculate KOL, from Eq. II.3.
- Calculate Δ from Eq. II.2.
- Having Δ , the goodness-of-fit index can be found from available tables for quantiles of the Kolmogorov test statistics (see, for example, *Practical Non-Parametric Statistics* by W.J. Conover, 2nd edition, page 462).

APPENDIX III

README INSTRUCTION FILE FOR THE WINDICE1/2 PACKAGE

- This is the user manual for the programs WINDICE1 & WINDICE2.
- The programs are interactive and easy to use.
- Many of the relationships used in the calculation of the loads are printed in the output file. For a more complete description of the methodology see the Ontario Hydro report entitled "Data base for weather related loads on overhead transmission lines in Ontario" by S.G. Krishnasamy and M. Tabatabai.
- The user may quit the program at any stage by pressing the (CTRL) and C keys simultaneously. The interruption may take place immediately, or the computer may finish the processing of the data existing in its buffer before exiting the program.
- An invalid response to a question usually prompts a repeat of the question.
- Execution procedure for program WINDICE2 will be discussed here.
- WINDICE1 has the same format as WINDICE2 except that it does not require information on the conductor diameter and span length.
- The first two plates of the program provide an introduction to the software.

PLATE 1:

PROGRAM " WINDICE2 "

PROBABILISTICS ANALYSIS OF ANNUAL EXTREME WIND AND ICE DATA
AND THEIR RESULTANT LOADS ON TRANSMISSION LINES
USING HISTORICAL DATA COLLECTED AT
30 ONTARIO WEATHER STATIONS

Note: This program requires the conductor length and
diameter. If no information on these parameters
are available, use program WINDICE1.

PLATE 2 :

FOR EACH STATION, THE PROGRAM WILL PROVIDE :
(1)-A table containing annual extreme wind and gust speeds and their corresponding loads at a user supplied height.
(2)-A table containing annual extreme equivalent radial ice, calculated from the ice accretion model, and the resultant vertical loads on conductors.
(3)-A table containing annual extreme wind and ice data and the resultant wind-on-ice loads at a user supplied height.
(4)-Extreme values of various wind and ice properties at a number of user supplied return periods. Also the upper and lower bounds of these values within a user supplied confidence level.
(5)-Wind speed and ice thickness frequency table at user supplied intervals.

- Plate 3 lists the names of the stations in the data base. The user must choose the station for which the analysis is required.

PLATE 3:

THE FOLLOWING STATIONS ARE IN DATABASE:

(1) ARMSTRONG A	(11) LONDON A	(21) SIOUX LOOKOUT
(2) ATIKOKAN	(12) MOUNT FOREST	(22) STIRLING
(3) BIG TROUT LAKE	(13) MUSKOKA A	(23) SUDBURY A
(4) CENTRALIA A	(14) NAKINA A	(24) THUNDER BAY A
(5) EARLTON A	(15) NORTH BAY A	(25) TIMMINS A
(6) GORE BAY A	(16) OTTAWA INT. A	(26) TORONTO INTL. A
(7) GRAHAM A	(17) OTTAWA ROCK CLIFFE A	(27) TRENTON A
(8) KAPUSKASING A	(18) PETAWAWA A	(28) WHITE RIVER
(9) KENORA A	(19) SAULT STE. MARIE A	(29) WIARTON A
(10) KILLALOE	(20) SIMCOE	(30) WINDSOR A
CHOOSE THE STATION WHOSE DATA YOU WISH TO USE.		

Enter corresponding number, 1 to 30 :

- Plate 4 asks for a name for the output file.
- You can include the drive destination of the output file, e.g., by entering B:\MANBY.DAT, the results will be stored in a data file named MANBY.DAT in drive B:.
- Note that if the floppy in drive A contains the software, it is write protected and cannot be the destination for the output file.

PLATE 4

Enter a name for the output file.

Output file -

- The user supplies the conductor diameter and the span length in plate 5. These values will be used to calculate the total loads (in lbs) on the transmission line due to extreme wind, ice and wind-on-ice conditions.
- Note that these information are not required for WINDICE1 where loads will be calculated for a line of unit length (ft) and unit diameter (in).

PLATE 5 :

Enter DIAM, the conductor diameter in inches:

DIAM -

Enter SPAN, the span length in feet

SPAN -

- Plate 6 requires the conductor height, H2, of the transmission line. If the conductor sag is not known use the height of the conductor attachment point (H_{cond}) as H2. If the sag is known then $H2 = H_{cond} - 2 \text{ sag}/3$ can provide a more accurate value for H2.
- The wind speeds at different heights are calculated using the power law relationship given in plate 7.
- For most stations, based on field observation of the weather station site, a value for FACH is suggested. Appearance of a "?" in the value of FACH implies that no field observation was available and the suggested FACH is a guess.

PLATE 6 :

Enter H2, the height in feet at which wind speeds are to be calculated:

H2 (Conductor height) -

PLATE 7 :

V2 (WIND SPEED AT H2) IS CALCULATED FROM EQUATION:

$V2 = V1 * (H2 / H1)^{FACH}$ where

H1 - height at which wind speed was measured

V1 - wind speed at height H1

FACH - power law exponent representative of terrain

AT " TORONTO INTL. A " A VALUE OF FACH = 0.16 IS SUGGESTED.

Enter the desired FACH value :

FACH -

- The relationships used for calculation of the wind/gust loads are given in plate 8.
- DCOEF is a constant that includes the conductor drag coefficient and the conversion factors of the relationship. Note that if a span factor other than 1.0 is to be used, its value can be incorporated in DCOEF.

PLATE 8 :

THE GUST SPEED IS CALCULATED FROM EQUATION:

$GUST = 1.29 * WIND + 5.80$, WHERE

WIND - WIND SPEED IN MPH

GUST - GUST SPEED IN MPH

THE TRANSVERSE LOADS DUE TO WIND OR GUST ARE CALCULATED FROM EQUATION :

$LOAD = DCOEF * SFAC * (WIND**2) * SPAN * DIAM/12$, WHERE

LOAD - WIND LOAD IN LB

SFAC - SPAN FACTOR - 1.0

WIND - WIND SPEED IN MPH

DIAM - CONDUCTOR DIAMETER IN INCHES

SPAN - SPAN LENGTH IN FT

DCOEF - A CONSTANT (USUALLY BETWEEN 0.0025 AND 0.003)

ENTER THE DESIRED VALUE FOR THE CONSTANT :

DCOEF -

- Statistical techniques are used to calculate annual extreme values at a number of return periods.
- The first question in plate 9 requires the number of return periods for which the extreme value calculations are to be performed. For example if extreme values corresponding to return periods of 10 and 50 years are required, respond "2" to this question (i.e., you are interested in 2 values of return periods) and then enter "10 50" in response to the second question requesting the actual values of the return periods, in years. The last question in this plate requires the confidence level at which the upper and lower bounds of the extreme values are calculated (e.g., enter 90 for 90% confidence level).
- NOTE: Calculation of the upper and lower confidence values are by far the most time consuming part of the program. In order to speed the calculations, enter 0 for the confidence level if the upper and lower bounds of the extreme values are not required.

PLATE 9:

CALCULATION OF EXTREME VALUES CORRESPONDING TO A NUMBER
OF USER SPECIFIED RETURN PERIODS

For how many return periods do you wish to calculate
the various annual extreme values (A maximum of 30)

N_{RP} - # of return periods -

Enter N_{RP} return periods at which the extreme values are to be calculated.

Return periods:

Enter confidence level (in %) :

Confidence level =

- The frequency of occurrence of combined wind and ice values for the station will be calculated and reported in a frequency table.
- A typical frequency table is shown below:

WIND SPEED (MPH)

	WIND	.0	7.5	15.0	20.0	25.0	30.0	40.0	50.0	60.0
	TO	TO	TO	TO	TO	TO	TO	TO	TO	TO
ICE	7.5	15.0	20.0	25.0	30.0	40.0	50.0	60.0	80.0	
RADIAL ICE (IN)	.0000	10	29	15	11	5	1	0	0	0
	TO	4.7	18.3	25.4	30.5	32.9	33.3	33.3	33.3	33.3
	.0100	4.7	18.3	25.4	30.5	32.9	33.3	33.3	33.3	33.3
	.0100	3	8	2	3	0	0	0	0	0
	TO	1.4	5.2	6.1	7.5	7.5	7.5	7.5	7.5	7.5
	.0200	6.1	23.5	31.5	38.0	40.4	40.8	40.8	40.8	40.8
	4.000	0	0	0	0	0	0	0	0	0
	TO	.0	.0	.0	.0	.0	.0	.0	.0	.0
	10.00	7.0	39.0	63.8	88.7	95.8	100.0	100.0	100.0	100.0

- The values that appear in a frequency cell are described bellow.

PLATE 10:

HINTS ON SETTING UP THE FREQUENCY TABLE

For the construction of the frequency table the following information is required :

nice = the number of radial ice intervals,
nvel = the number of wind speed intervals,
radial ice values for the intervals,
wind speeds for the intervals.

For example, for a table with radial ice intervals of: 0.0 to 0.2, 0.2 to 0.4, 0.4 to 0.6, 0.6 to 1.0 and 1.0 to 10. (in), and with wind speed intervals of: 0 to 10, 10 to 20, 20 to 40 and 40 to 200 mph, we choose :

ni = 5,
radial ice values = 0 .2 .4 .6 1 10 <----- nice+1 values,
nv = 4 and
wind speeds = 0 10 20 40 200 <----- nvel+1 values

Note that for a complete frequency table, the minimum and maximum values for wind speed and ice thickness should be set at 0.0 and unreasonably large values, respectively.

- The program then asks for information on the desired frequency table. These questions and the answers required for setting up the following sample frequency table are shown below.

Enter the NUMBER of ice thickness intervals: ni = 3
Enter 4 ice thickness VALUES (in): Radial ice values :0 .2 .4 1
Enter the NUMBER of wind speed intervals nv = 4
Enter 5 wind speed VALUES (mph): Wind speeds : 0 10 30 60 100

WIND SPEED (MPH)

	WIND	.0	10.0	30.0	60.0
		TO	TO	TO	TO
ICE		10.0	30.0	60.0	100.0
RADIAL	.0000	31	138	6	0
	TO	14.6	79.3	82.2	82.2
	.200	14.6	79.3	82.2	82.2
	.200	0	28	2	0
	TO	.0	13.1	14.1	14.1
	.40	14.6	92.5	96.2	96.2
	.400	0	7	1	0
	TO	.0	3.3	3.8	3.8
ICE	1.00	14.6	95.8	100.0	100.0

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DEFINITIONS

The important definitions used in this report are listed below.

Hourly mean wind velocity	-	Velocity averaged over a one hour period
Maximum wind velocity	-	Maximum velocity over a one hour period
Transverse load on conductor	-	Load acting on horizontal plane
Vertical load on conductor	-	Load acting on vertical plane
Span factor	-	<u>Measured transverse wind load</u> Calculated transverse wind load
Return period	-	Average interval of time between successive occurrence of a value

SYMBOLS

A_h	-	ice accumulation on horizontal vertical surface
A_v	-	ice accumulation on vertical surface
$A_{v,i}$	-	ice accumulation on vertical surface during the i^{th} hour of an ice storm
B	-	location parameter
C_{DC}	-	conductor drag coefficient
C	-	scale parameter
D	-	conductor diameter
g	-	precipitation intensity
GOF	-	goodness-of-fit index
H_N	-	height at which wind speed was measured
H	-	mean conductor height
K_I	-	conversion factor to calculate ice load from load on a 1 inch diameter conductor
K_{WI}	-	conversion factor to calculate wind-on-ice load from load on a 1 inch diameter conductor
k	-	a correction factor used in the ice model (function of conductor size and temperature, $k = 1/(0.1858 + 0.156 \cdot 2 \cdot r)$ at about $0^\circ C$
L	-	span length
$P(X)$	-	cumulative density function of variable X
P_C	-	calculated load
P_I	-	ice load
$P_{I(1)}$	-	ice load on a one-inch conductor
P_M	-	measured wind pressure on conductor
P_W	-	wind load
P_W	-	wind pressure on conductor
P_{WI}	-	wind-on-ice load
$P_{WI(1)}$	-	wind-on-ice load on a one-inch conductor
r	-	radius of conductor
RP	-	return period
RV	-	reduced variate
S	-	span factor
t	-	equivalent radial ice thickness
t_I	-	equivalent radial ice thickness, corresponding to ice only conditions
t_{WI}	-	equivalent radial ice thickness, corresponding to combined wind and ice conditions
V	-	wind speed at the mean conductor height
V_g	-	gust speed
V_N^g	-	wind speed at height H_N
V	-	wind speed at the mean conductor height
w	-	density of ice
α	-	power law exponent representative of terrain
ρ	-	air density
σ	-	standard deviation

TABLE 1

FACTORS FOR VARIOUS TERRAINS

Terrain type	Factor(α) *
1) Open terrain with very few obstacles, eg., open grass or farm-land with few trees, hedgerows and other barriers etc.; prairie, tundra shores and low islands of inland lakes; deserts	0.16
2) Terrain uniformly covered with obstacles 0 to 50 ft in height; eg., residential suburbs; small towns; woodland and shrubs, small fields with bushes, trees and hedges.	0.28
3) Terrain with large and irregular objects; eg., centers of large cities, very broken country with many windbreaks of tall trees, etc.	0.40

* see Eq.2

TABLE 2

DETAILS OF THE WEATHER STATIONS CONSIDERED IN THE DATA BASE

STATION NAME	IN SERVICE		ANEMOMETER HEIGHT (FT)	TERRAIN FACTOR (α)	NO. OF YEARS OF DATA
	FROM	TO			
ARMSTRONG A	JAN53	AUG56	24.3	0.16*	16
ARMSTRONG A	SEP56	DEC68	24.9	0.16*	
ATIKOKAN	JUL66	AUG68	10	0.19	18
ATIKOKAN	SEP68	OCT74	13	0.19	
ATIKOKAN	NOV74	DEC83	13	0.19	
BIG TROUT LAKE	JAN66	AUG75	1	0.19	18
BIG TROUT LAKE	SEP75	DEC83	13.4	0.19	
CENTRALIA A	JAN53	NOV53	15.2	0.16*	14
CENTRALIA A	DEC53	DEC58	24	0.16*	
CENTRALIA A	JAN59	OCT60	27	0.16*	
CENTRALIA A	NOV60	APR65	27.4	0.16*	
CENTRALIA A	MAY65	JAN66	20.4	0.16*	
EARLTON A	JAN53	MAY51	15.2	0.16	28
EARLTON A	JUN51	DEC80	19.5	0.16	
GORE BAY A	JAN53	SEP63	13.1	0.16	31
GORE BAY A	OCT63	DEC80	9.9	0.16	
GRAHAM A	JAN53	JUL64	15.8	0.16*	15
GRAHAM A	AUG64	DEC67	15.8*	0.16*	
KAPUSKASING A	JAN53	AUG78	18.9	0.19	31
KAPUSKASING A	SEP78	DEC83	9.8	0.19	
KENORA A	JAN53	MAR56	27.4	0.16	31
KENORA A	APR56	MAR68	26.0	0.16	
KENORA A	APR68	DEC83	10.0	0.16	
KILLALOE	JAN53	DEC72	17.3	0.16	20
LONDON A	JAN53	JAN67	12.5	0.16	31
LONDON A	FEB67	DEC83	10.0	0.16	
MOUNT FOREST	JAN62	MAR70	10.0	0.16	15
MOUNT FOREST	APR70	DEC76	10.5	0.16	
MUSKOKA A	JAN53	OCT58	13.4	0.19	28
MUSKOKA A	NOV58	OCT69	29.3	0.19	
MUSKOKA A	NOV69	DEC83	26.9	0.19	
NAKINA A	JAN53	MAR59	14.3	0.16*	15
NAKINA A	APR59	NOV67	15.8	0.16*	

* - Assumed

TABLE 2 (cont.)

STATION NAME	IN SERVICE		ANEMOMETER HEIGHT (FT)	TERRAIN FACTOR (α)	NO. OF YEARS OF DATA
	FROM	TO			
NORTH BAY A	JAN53	NOV63	19.5	0.19	31
NORTH BAY A	DEC63	DEC83	12.6	0.19	
OTTAWA INT. A	JAN53	DEC83	10.0	0.16	31
OTTAWA ROCK CLIFFE	JAN53	JUL71	15.2	0.16	17
PETAWAWA A	JAN71	JUN74	22.0	0.16*	13
PETAWAWA A	JUL74	DEC83	10.0	0.16*	
SAULT STE. MARIE A	AUG61	OCT73	12.8	0.16	23
SAULT STE. MARIE A	NOV73	DEC83	11.6	0.16	
SIMCOE	JAN62	DEC76	10.0	0.16	22
SIOUX LOOKOUT	JAN53	DEC66	24.4	0.19	31
SIOUX LOOKOUT	JAN67	DEC83	10.0	0.19	
STIRLING	JAN53	APR68	13.7	0.16*	16
STIRLING	MAY68	DEC78	14.0	0.16*	
SUDBURY A	JAN54	MAY67	14.6	0.16	30
SUDBURY A	JUN67	DEC83	10.0	0.16	
THUNDER BAY A	JAN53	DEC55	24.4	0.19	31
THUNDER BAY A	JAN56	FEB58	13.7	0.19	
THUNDER BAY A	MAR58	OCT65	11.3	0.19	
THUNDER BAY A	NOV65	DEC83	10.0	0.19	
TIMMINS A	APR55	OCT74	10.7	0.16	28
TIMMINS A	NOV74	DEC82	9.9	0.16	
TORONTO INTL. A	JAN53	APR64	17.0	0.16	31
TORONTO INTL. A	MAY64	DEC83	10.0	0.16	
TRENTON A	JAN53	MAR59	18.6	0.16	31
TRENTON A	APR59	SEP62	22.9	0.16	
TRENTON A	OCT62	DEC83	10.0	0.16	
WHITE RIVER	JAN53	NOV62	14.0	0.16*	
WHITE RIVER	DEC62	MAY76	10.0	0.16*	
WIARTON A	JAN53	FEB71	13.4	0.19	31
WIARTON A	MAR71	DEC83	10.0	0.19	
WINDSOR A	JAN53	SEP57	18.1	0.19	31
WINDSOR A	OCT57	MAY62	6.4	0.19	
WINDSOR A	JUN62	DEC83	10.0	0.19	

* - Assumed

TABLE 3

RESULTS OF AES MODEL EVALUATION FOR TWO STORMS

Location	Storm Start Date	Storm Duration (hrs)	Measured Max. Equiv. Radial Ice(in)	AES Modelled Equiv. Radial Ice(in)
London	Dec. 3 1978	9	0.272	0.299
Orange- Ville	Mar. 17 1982	16	0.201	0.264

TABLE 4

COMPARISON OF PREDICTED AND MEASURED RETURN PERIOD
ESTIMATES OF ICE ACCRETION THICKNESS (IN) FOR
VARIOUS RETURN PERIODS

Return Period (years)		2	5	10
Data Sources				
Montreal	(Measured) ¹	0.295	0.437	0.531
	(AES model)	0.350	0.465	0.539
London	(Measured) ²	0.114	0.201	0.260
	(AES model)	0.268	0.346	0.398

1 - Annual max. ice thickness on a one inch cylinder

2 - Annual max. equiv. radial ice on 1380 ft span

TABLE 5

ANNUAL EXTREME WIND PRESSURES FOR
TORONTO INTERNATIONAL AIRPORT*

YEAR	HOURLY MEAN	GUST SPEED (MPH)	WIND PRESSURE (PSF)	
	WIND SPEED (MPH)		FROM MEAN WIND	FROM GUST WIND
1953	43.4	61.8	5.6	11.5
1954	52.6	73.6	8.3	16.3
1955	45.7	64.7	6.3	12.6
1956	51.4	72.1	7.9	15.6
1957	36.6	53.0	4.0	8.4
1958	44.0	62.6	5.8	11.8
1959	55.4	77.3	9.2	17.9
1960	34.8	50.8	3.6	7.7
1961	39.4	56.7	4.7	9.6
1962	34.3	50.0	3.5	7.5
1963	44.0	62.6	5.8	11.8
1964	49.7	70.0	7.4	14.7
1965	37.9	54.7	4.3	9.0
1966	37.9	54.7	4.3	9.0
1967	36.0	52.3	3.9	8.2
1968	39.8	57.2	4.8	9.8
1969	34.2	50.0	3.5	7.5
1970	39.8	57.2	4.8	9.8
1971	37.9	54.7	4.3	9.0
1972	42.9	61.2	5.5	11.2
1973	36.0	52.3	3.9	8.2
1974	46.0	65.2	6.4	12.8
1975	46.0	65.2	6.4	12.8
1976	44.1	62.7	5.8	11.8
1977	36.7	53.2	4.0	8.5
1978	43.5	62.0	5.7	11.5
1979	50.3	70.8	7.6	15.0
1980	43.5	62.0	5.7	11.5
1981	40.4	58.0	4.9	10.1
1982	43.5	62.0	5.7	11.5
1983	36.7	53.2	4.0	8.5

* Terrain type - 1 (see Table 1),
 Height at which pressure was calculated - 33.0 ft

TABLE 6

ANNUAL EXTREME ICE LOADS FOR TORONTO INTERNATIONAL AIRPORT

YEAR	HORIZ. ICE	VERT. ICE (IN)	EQVT. ICE (IN)	RADIAL ICE LOAD* (LB/FT)
1953	.38	.40	.31	.50
1954	.09	.23	.16	.22
1955	.13	.21	.16	.22
1956	.27	.34	.26	.40
1957	.08	.08	.07	.10
1958	.08	.07	.07	.09
1959	.39	.70	.42	.73
1960	.94	1.76	.81	1.81
1961	.59	1.23	.62	1.24
1962	.36	.43	.31	.51
1963	.12	.20	.15	.21
1964	.16	.32	.21	.32
1965	.47	1.07	.55	1.06
1966	.26	.37	.26	.41
1967	.24	.49	.30	.49
1968	1.49	1.86	.91	2.17
1969	.11	.31	.20	.30
1970	.11	.17	.13	.18
1971	.43	.86	.48	.88
1972	.28	.72	.40	.70
1973	.09	.11	.10	.13
1974	.19	.44	.27	.44
1975	.18	.32	.22	.34
1976	.17	.31	.21	.32
1977	.13	.14	.13	.18
1978	.15	.28	.19	.29
1979	.09	.23	.16	.22
1980	.08	.11	.09	.12
1981	.00	.00	.00	.00
1982	.34	.32	.27	.42
1983	.20	.44	.28	.44

* Ice load is calculated for a one inch diameter conductor

TABLE 7

ANNUAL EXTREME WIND-ON-ICE LOADS FOR
TORONTO INTERNATIONAL AIRPORT*

YEAR	HORIZ.	VERT.	EQVT.	RADIAL	HOURLY MEAN WIND SPEED (MPH)	LOAD (LB/FT) ⁺	
	ICE (IN)	ICE (IN)	ICE (IN)			MEAN WIND	GUST WIND
1953	.38	.40	.31		18.3	.14	.35
1954	.00	.00	.00		31.4	.25	.54
1955	.00	.00	.00		22.9	.13	.31
1956	.03	.07	.05		36.6	.37	.77
1957	.04	.05	.04		22.3	.13	.32
1958	.03	.05	.04		17.7	.08	.22
1959	.29	.31	.25		22.3	.19	.45
1960	.11	.15	.12		26.9	.22	.51
1961	.59	1.23	.62		36.6	.75	1.57
1962	.01	.01	.01		27.4	.19	.43
1963	.11	.08	.09		36.6	.39	.82
1964	.16	.32	.21		26.1	.24	.56
1965	.47	1.07	.55		26.8	.58	.85
1966	.03	.08	.06		24.9	.17	.40
1967	.17	.42	.26		24.9	.24	.55
1968	1.49	.86	.91		28.0	.55	1.24
1969	.11	.31	.20		24.3	.21	.48
1970	.05	.17	.11		31.7	.31	.67
1971	.43	.86	.48		26.1	.33	.76
1972	.28	.72	.40		26.1	.31	.70
1973	.09	.11	.10		31.7	.30	.65
1974	.13	.30	.20		29.9	.31	.69
1975	.16	.30	.20		37.3	.49	1.02
1976	.06	.17	.12		23.0	.16	.39
1977	.13	.14	.13		34.8	.38	.81
1978	.15	.28	.19		18.7	.12	.31
1979	.02	.07	.05		25.5	.18	.41
1980	.00	.01	.00		28.6	.21	.46
1981	.00	.00	.00		16.2	.07	.18
1982	.18	.42	.27		25.5	.25	.57
1983	.20	.44	.28		24.3	.23	.54

* Terrain type 1 (See Table 1)

Height at which wind-on-ice load is calculated = 33.0 ft

+ Wind-on-ice load is calculated for a one inch conductor

TABLE 8

CONVERSION FACTORS, K_T , FOR CALCULATING ICE LOAD
ON ANY CONDUCTOR FROM THE ICE LOAD
ON A ONE-INCH DIAMETER CONDUCTOR

CONDUCTOR DIAMETER (in)	RADIAL ICE THICKNESS (in)							
	1/8	1/4	1/2	3/4	1	1.5	2	3
1/4	0.333	0.4	0.5	0.57	0.625	0.7	0.75	0.813
3/8	0.444	0.5	0.583	0.643	0.688	0.750	0.792	0.844
1/2	0.55	0.6	0.667	0.714	0.75	0.8	0.833	0.875
3/4	0.778	0.8	0.833	0.857	0.875	0.9	0.917	0.938
1	1.	1.	1.	1.	1.	1.	1.	1.
1 1/2	1.44	1.4	1.33	1.29	1.25	1.2	1.167	1.125
2	1.889	1.8	1.67	1.57	1.5	1.4	1.33	1.25

TABLE 9

CONVERSION FACTORS, K_{WI} , FOR CALCULATING WIND-ON-ICE LOAD
ON ANY CONDUCTOR FROM THE WIND-ON-ICE LOAD
ON A ONE-INCH DIAMETER CONDUCTOR

CONDUCTOR DIAMETER (in)	RADIAL ICE THICKNESS (in)							
	1/8	1/4	1/2	3/4	1	1.5	2	3
1/4	0.4	0.5	0.625	0.7	0.75	0.813	0.85	0.893
3/8	0.5	0.583	0.688	0.750	0.792	0.844	0.875	0.91
1/2	0.6	0.667	0.75	0.8	0.833	0.875	0.9	0.929
3/4	0.8	0.833	0.875	0.9	0.917	0.938	0.95	0.964
1	1.	1.	1.	1.	1.	1.	1.	1.
1 1/2	1.4	1.33	1.25	1.2	1.167	1.125	1.1	1.07
2	1.8	1.67	1.5	1.4	1.33	1.25	1.2	1.143

TABLE 10

STATISTICAL PARAMETERS FOR THE PROBABILISTIC ANALYSIS
OF THE WEATHER DATA

STATION NAME	TERRAIN FACTOR	YEARS DATA	WIND DATA			ICE DATA			WIND-ON-ICE DATA		
			B	C	G.O.F.	B	C	G.O.F.	B	C	G.O.F.
ARMSTRONG A	.16	16	28	2.9	72	.09	.08	78	.1	.02	96
ATIKOKAN	.19	18	23	2.1	91	.08	.07	47	.09	.03	100
BIG TROUT LAKE	.19	18	33	2.5	98	.08	.08	88	.17	.07	97
CENTRALIA A	.16	14	43	5.8	100	.23	.12	100	.23	.14	100
EARLTON A	.16	28	31	3.9	38	.19	.12	99	.14	.04	40
GORE BAY A	.16	31	39	4.9	93	.17	.13	83	.22	.1	61
GRAHAM A	.16	15	33	3.1	94	.09	.07	96	.15	.05	100
KAPUSKASING A	.19	31	29	3.1	51	.13	.09	98	.12	.04	81
KENORA A	.16	31	29	3.5	91	.1	.1	51	.11	.04	86
KILLALOE	.16	20	35	4.7	81	.15	.1	100	.11	.05	82
LONDON A	.16	31	39	4.7	80	.3	.15	97	.33	.14	75
MOUNT FOREST	.16	15	35	3.8	100	.33	.12	97	.33	.08	91
MUSKOKA A	.19	28	25	4.1	93	.24	.13	100	.13	.05	99
NAKINA A	.16	15	28	2.7	49	.07	.07	47	.1	.02	41
NORTH BAY A	.19	31	30	3.2	40	.27	.13	95	.21	.08	91
OTTAWA INT. A	.16	31	36	3.9	99	.31	.12	89	.25	.1	88
OTTAWA ROCK CLIFFE	.16	12	34	3.4	96	.26	.1	99	.19	.07	100
PETAWAWA A	.16	13	29	3.6	99	.2	.08	96	.11	.05	100
SAULT STE. MARIE A.	.16	23	40	4.6	100	.16	.15	83	.18	.08	99
SIMCOE	.16	22	36	5.5	89	.26	.18	99	.19	.09	100
SIOUX LOOKOUT	.19	31	27	3.5	89	.07	.07	50	.1	.04	48
STIRLING	.16	16	33	4.8	77	.21	.13	100	.15	.07	100
SUDBURY A	.16	30	42	5.3	97	.27	.14	93	.33	.13	39
THUNDER BAY A	.19	31	33	4.8	86	.1	.12	43	.14	.08	83
TIMMINS A	.16	28	30	4.5	23	.15	.1	97	.13	.05	90
TORONTO INTL. A	.16	31	39	4.5	83	.19	.14	77	.21	.1	96
TRENTON A	.16	31	39	5.3	96	.22	.12	100	.14	.08	100
WHITE RIVER	.16	23	23	3.6	85	.07	.06	93	.07	.04	29
WIARTON A	.19	31	38	3.8	95	.18	.09	96	.19	.07	100
WINDSOR A	.19	31	39	6.	100	.23	.17	99	.24	.11	77
For all the stations :											
AVG.			83			86			83		
MAX.			100			100			100		
MIN.			23			43			29		

- B and C are location and space parameters in Gumble Type I equation:
 $F(y) = \exp\{-\exp[-(y-B)/C]\}$

- G.O.F. is the Kolmogorov-Smirnov goodness-of-fit index (in %)

- Ice thickness and wind-on-ice load are calculated for a one inch conductor,

- Height at which wind related values are calculated = 33 ft

TABLE 11

EXTREME VALUES FOR SELECTED RETURN PERIODS
FOR TORONTO INTERNATIONAL AIRPORT*

RETURN PERIOD (YRS)	WIND SPEED (MPH)			WIND PRESSURE (PSF)			GUST SPEED (MPH)			GUST PRESSURE (PSF)		
	UP. 95	MEAN	LOW. 95	UP. 95	MEAN	LOW. 95	UP. 95	MEAN	LOW. 95	UP. 95	MEAN	LOW. 95
10.0	54.8	49.7	46.7	9.0	7.4	6.5	76.4	69.9	66.0	17.5	14.6	13.1
20.0	59.2	52.9	49.3	10.5	8.4	7.3	82.2	74.1	69.4	20.3	16.5	14.4
40.0	63.6	56.1	51.8	12.2	9.5	8.1	87.9	78.2	72.6	23.2	18.3	15.8
50.0	65.1	57.2	52.6	12.7	9.8	8.3	89.7	79.5	73.7	24.2	19.0	16.3
60.0	66.2	58.0	53.3	13.2	10.1	8.5	91.2	80.6	74.5	25.0	19.5	16.7
80.0	68.0	59.3	54.3	13.9	10.5	8.9	93.6	82.3	75.9	26.3	20.3	17.3
100.0	69.4	60.3	55.1	14.5	10.9	9.1	95.4	83.6	76.9	27.3	21.0	17.7
200.0	73.8	63.5	57.6	16.3	12.1	10.0	101.0	87.7	80.1	30.6	23.1	19.3
500.0	79.6	67.6	60.9	19.0	13.7	11.1	108.4	93.0	84.3	35.3	26.0	21.3

RETURN PERIOD (YRS)	EQUIVALENT ICE (IN)			ICE LOAD (LBS/FT)			WIND-ON-ICE LOAD (LBS/FT)		
	UP. 95	MEAN	LOW. 95	UP. 95	MEAN	LOW. 95	UP. 95	MEAN	LOW. 95
10.0	.66	.50	0.41	1.36	.94	.72	0.55	.44	.37
20.0	.80	.60	0.49	1.78	1.20	.91	0.65	.51	.43
40.0	.93	.70	0.57	2.24	1.48	1.11	0.75	.58	.48
50.0	.98	.73	0.59	2.40	1.57	1.17	0.78	.60	.50
60.0	1.01	.76	0.61	2.53	1.65	1.23	0.81	.62	.52
80.0	1.07	.80	0.64	2.74	1.78	1.32	0.85	.65	.54
100.0	1.11	.83	0.67	2.91	1.88	1.39	0.88	.68	.56
200.0	1.24	.92	0.74	3.47	2.21	1.61	0.98	.75	.6
500.0	1.42	.05	0.84	4.27	2.67	1.93	1.11	.84	.69

* Terrain type 1 (See Table 1)

Low 95 - lower 95% confidence limit

upper 95 - upper 95% confidence limit

Wind-on-ice load is calculated for a one inch conductor

Height at which wind related values are calculated = 33 ft

TABLE 12

50-YEAR RETURN PERIOD WEATHER-RELATED DATA

STATION NAME	WIND SPEED (MPH)	WIND PRESSURE (PSF)	GUST SPEED (MPH)	GUST PRESSURE (MPH)	RADIAL ICE (IN)	ICE LOAD (LB/FT)	WIND-ON- ICE LOAD (LB/FT)
ARMSTRONG A	39.4	4.66	56.7	9.63	0.38	0.65	0.19
ATIKOKAN	31.7	3.01	46.7	6.53	0.37	0.62	0.19
BIG TROUT LAKE	42.1	5.33	60.2	10.86	0.41	0.71	0.43
CENTRALIA A	65.6	12.89	90.4	24.50	0.72	1.53	0.84
EARLTON A	45.4	6.17	64.3	12.41	0.65	1.33	0.31
ORE BAY A	57.6	9.94	80.1	19.23	0.68	1.43	0.62
GRAHAM A	44.9	6.06	63.8	12.20	0.38	0.66	0.33
KAPUSKASING A	41.6	5.19	59.4	10.60	0.48	0.88	0.26
KENORA A	42.1	5.31	60.1	10.83	0.48	0.87	0.26
KILLALOE	52.9	8.40	74.1	16.45	0.53	1.02	0.30
LONDON A	57.8	10.04	80.4	19.40	0.91	2.18	0.87
MOUNT FOREST	49.9	7.46	70.1	14.75	0.81	1.83	0.63
MUSKOKA A	40.7	4.97	58.3	10.19	0.77	1.68	0.32
NAKINA A	38.7	4.50	55.7	9.32	0.34	0.57	0.18
NORTH BAY A	43.0	5.54	61.2	11.25	0.78	1.72	0.51
OTTAWA INT. A	51.7	8.02	72.5	15.77	0.78	1.74	0.65
OTTAWA ROCK CLIFFE	47.2	6.69	66.7	13.35	0.64	1.31	0.47
PETAWAWA A	42.8	5.50	61.1	11.18	0.52	0.99	0.33
SAULT STE. MARIE A.	57.8	10.04	80.4	19.40	0.76	1.66	0.48
SIMCOE	57.6	9.94	80.0	19.22	0.97	2.36	0.54
SIOUX LOOKOUT	41.0	5.04	58.7	10.32	0.36	0.61	0.25
STIRLING	50.7	7.72	71.2	15.23	0.70	1.49	0.42
SUBURY A	62.3	11.64	86.2	22.27	0.81	1.81	0.83
THUNDER BAY A	52.2	8.19	73.2	16.07	0.58	1.13	0.44
TIMMINS A	48.1	6.95	67.9	13.82	0.55	1.07	0.31
TORONTO INTL. A	57.2	9.80	79.5	18.97	0.73	1.57	0.60
TRENTON A	60.3	10.91	83.6	20.96	0.70	1.47	0.37
WHITE RIVER	37.2	4.15	53.8	8.67	0.33	0.54	0.21
WIARON A	52.8	8.36	73.9	16.37	0.55	1.06	0.45
WINDSOR A	63.9	12.25	88.2	23.35	0.90	2.11	0.68
For all the stations	AVG.	49.2	7.49	69.3	14.77	0.62	0.44
	MAX.	65.6	12.89	90.4	24.50	0.97	0.87
	MIN.	31.7	3.01	46.7	6.53	0.33	0.18
	COV.	0.18	0.35	0.16	0.32	0.30	0.44

- Ice thickness and wind-on-ice load are calculated for a one inch conductor

- Height at which wind related values are calculated - 33 ft

TABLE 13

WIND SPEED AND ICE THICKNESS FREQUENCY TABLE
FOR TORONTO INTERNATIONAL AIRPORT

Wind speeds (mph) are at standard height - 33 ft

Ice thicknesses (inch) were obtained from AES ice accretion model for a 1-in conductor 213 storms, occurring over a period of 31 years, are considered.

ICE	0.0	.125	.025	0.05	.075	.1	.125	.15	.2	.25	.3	.4	.5	.6	.8	1.
to	to	to	to	to	to	to	to	to	to	to	to	to	to	to	to	to
WIND	.0125	.025	0.05	.075	.1	.125	.15	.2	.25	.3	.4	.5	.6	.8	1.0	10
0	39	11	4	8	7	5	1	4	0	3	1	0	0	0	0	0
to	18.3	23.5	25.4	29.1	32.4	34.7	35.2	37.1	37.1	38.5	39.0	39.0	39.0	39.0	39.0	39
15	18.3	23.5	25.4	29.1	32.4	34.7	35.2	37.1	37.1	38.5	39.0	39.0	39.0	39.0	39.0	39
15	15	3	4	2	5	1	6	4	3	6	2	1	0	0	1	0
to	7.0	8.5	10.3	11.3	13.6	14.1	16.9	18.8	20.2	23.0	23.9	24.4	24.4	24.9	24.9	25
20	25.4	31.9	35.7	40.4	46.0	48.8	52.1	55.9	57.3	61.5	62.9	63.4	63.4	63.4	63.4	63
20	12	4	5	2	5	2	4	6	3	2	1	0	0	0	0	0
to	5.6	7.5	10.4	13.1	14.1	16.4	17.4	19.2	22.1	23.5	24.4	24.9	24.9	24.9	24.9	25
25	31	39.4	45.6	53.5	60.1	65.3	69.5	75.1	79.3	85.0	87.3	88.3	88.3	88.3	88.7	89
25	5	0	0	1	1	1	0	1	0	1	1	2	0	1	0	0
to	2.3	2.1	2.3	2.8	3.3	3.8	3.8	4.2	4.2	4.7	5.2	6.1	6.6	6.6	7.0	7.0
30	33.3	41.8	48.8	56.3	63.4	69.0	73.2	79.3	83.6	89.7	92.5	94.4	94.8	94.8	95.8	96
30	1	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0
to	0.5	0.5	0.5	0.5	0.9	1.4	1.9	1.9	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
35	33.8	42.3	49.3	56.8	64.3	70.4	75.1	81.2	85.9	92.0	94.8	96.7	97.2	97.2	98.1	98
35	0	0	0	1	1	0	0	0	1	0	0	0	0	1	0	0
to	0.0	0.0	0.0	0.5	0.9	0.9	0.9	0.9	1.4	1.4	1.4	1.4	1.4	1.9	1.9	1.9
40	33.8	42.3	49.3	57.3	65.3	71.4	76.1	82.2	87.3	93.4	96.2	98.1	98.6	99.1	100.	100
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to	0.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	33.8	42.3	49.3	57.3	65.3	71.4	76.1	82.2	87.3	93.4	96.2	98.1	98.6	99.1	100.	100
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	33.8	42.3	49.3	57.3	65.3	71.4	76.1	82.2	87.3	93.4	96.2	98.1	98.6	99.1	100.	100
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
to	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
200	33.8	42.3	49.3	57.3	65.3	71.4	76.1	82.2	87.3	93.4	96.2	98.1	98.6	99.1	100.	100

TABLE 14

DETAILS OF POWER LINES AT TOWER LOAD MEASUREMENT SITES

LOCATION AND SERVICE PERIOD	kV	APPROX. LINE * ORIENT.	AVG. SPAN LGTH (FT)	TOWER HEIGHT (FT)	CONDUCTOR SIZE (IN)	SITE DESCRIPTION	SPAN FACTOR CALCULATED?
ORANGE- VILLE 1975-83	230	115	1514	152.	1.34+	SLIGHTLY ROLLING FARMLAND WITH SCATTERED TREES AND BUSHES	YES
ORANGE- VILLE 1985-	45	170	267	56.	0.87		NO
LONDON 1976-	230	0	1379	142.	1.1 ⁺	FARMLAND WITH DENSE BUSHES, BORDERED ONE SIDE BY HOUSES	YES
BRANT- FORD 1978-82	230	60	1082	112.	1.34 ⁺	FLAT FARMLAND WITH SCATTERED TREES AND HOUSES	YES
NANTI- COKE 1976- 1980-	230 500	165 165	712 712	132. 122.	1.61 ⁺ 0.95 [@]	FLAT FARMLAND WITH SCATTERED TREES AND HOUSES	YES
PETERBO- ROUGH 1984-	230	128	963	149.	1.1 ⁺	SLIGHTLY ROLLING FARMLAND WITH SCATTERED TREES AND BUSHES	NO

* DEGREES CLOCKWISE FROM NORTH

+ SINGLE STEEL REINFORCED ALUMINUM CONDUCTOR

@ STEEL REINFORCED ALUMINUM 4 CONDUCTOR BUNDLE



Fig 1. Weather stations in Ontario where complete wind and modelled ice and wind-on-ice data are available

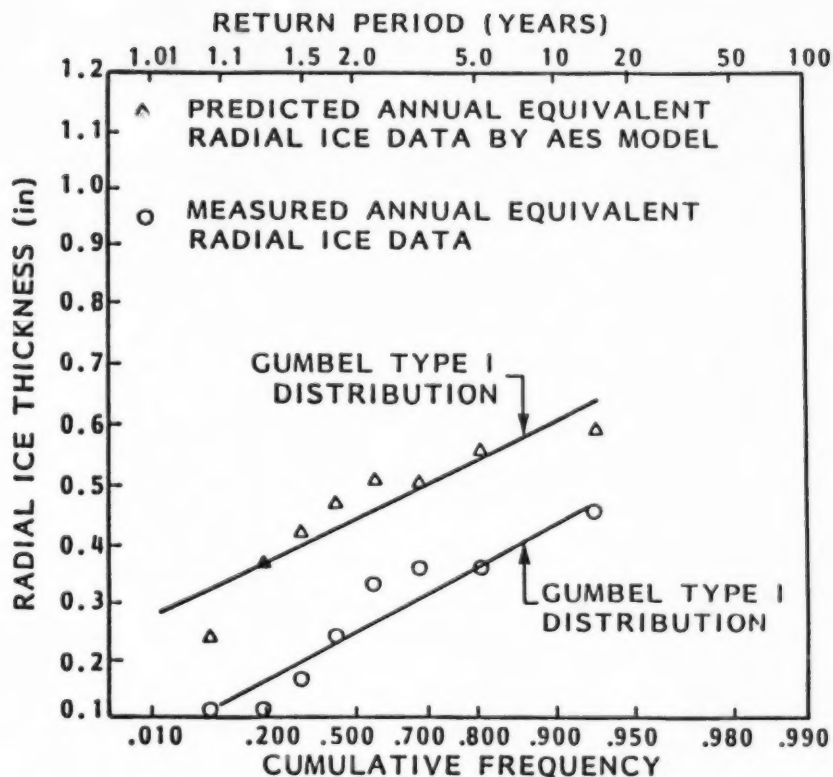


FIGURE 2

COMPARISON OF PREDICTED AND MEASURED ANNUAL
EXTREME ICE ACCRETION DATA FOR LONDON, ONTARIO
(YEARS 1977-84)

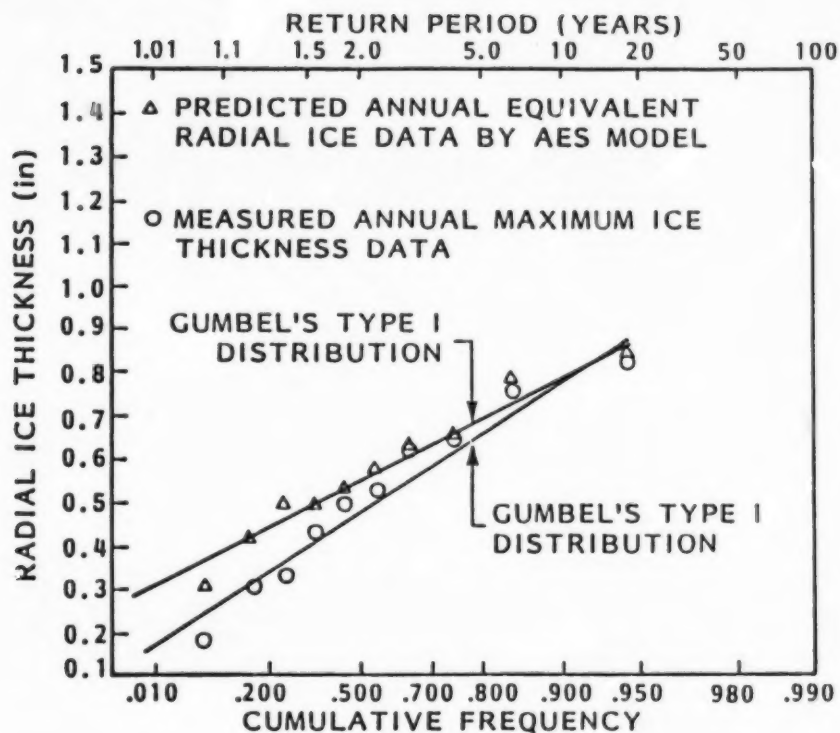


FIGURE 3

COMPARISON OF PREDICTED AND MEASURED ANNUAL
EXTREME ICE ACCRETION DATA FOR MONTREAL, QUEBEC
(YEARS 1975-1984)

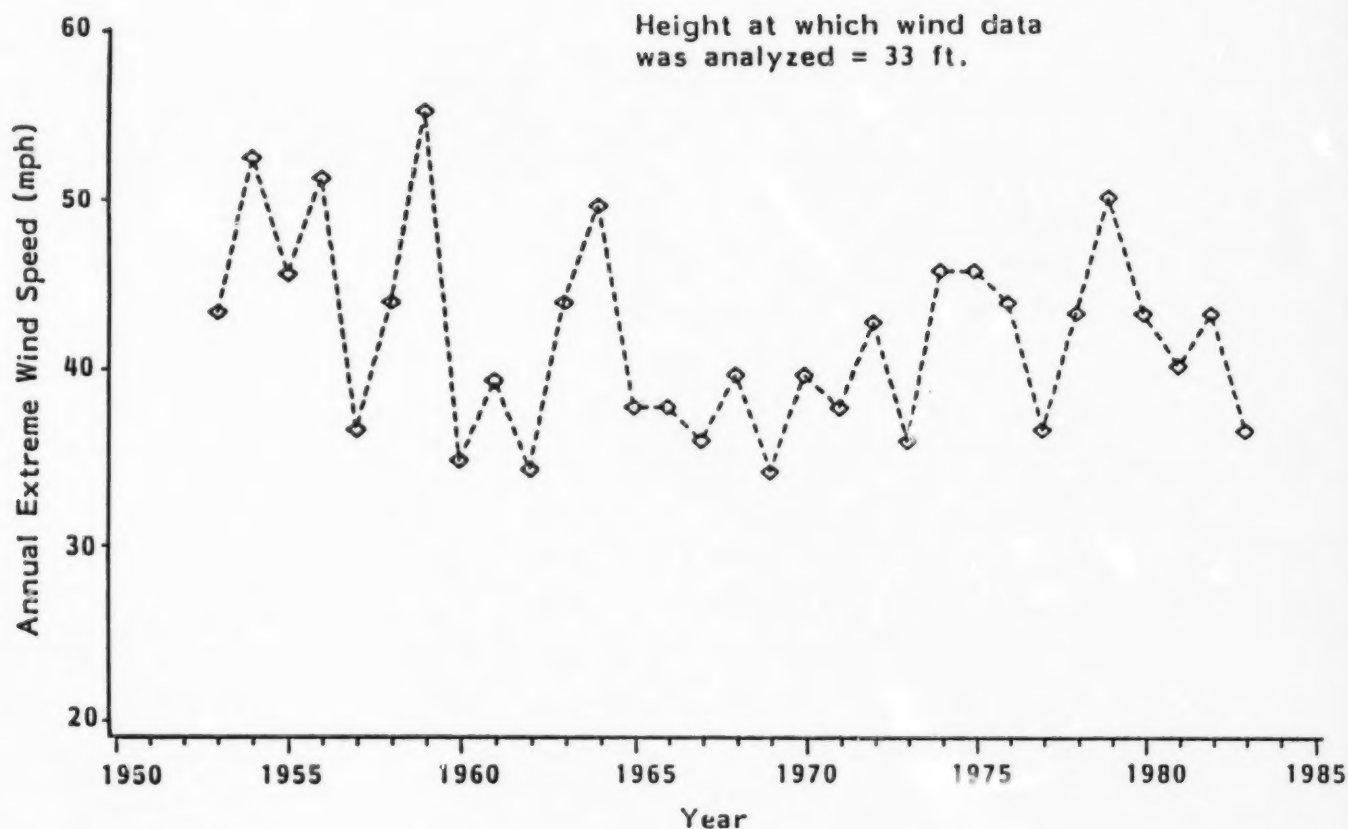


Figure 4. Annual extreme hourly mean wind speed variation for Toronto International Airport.

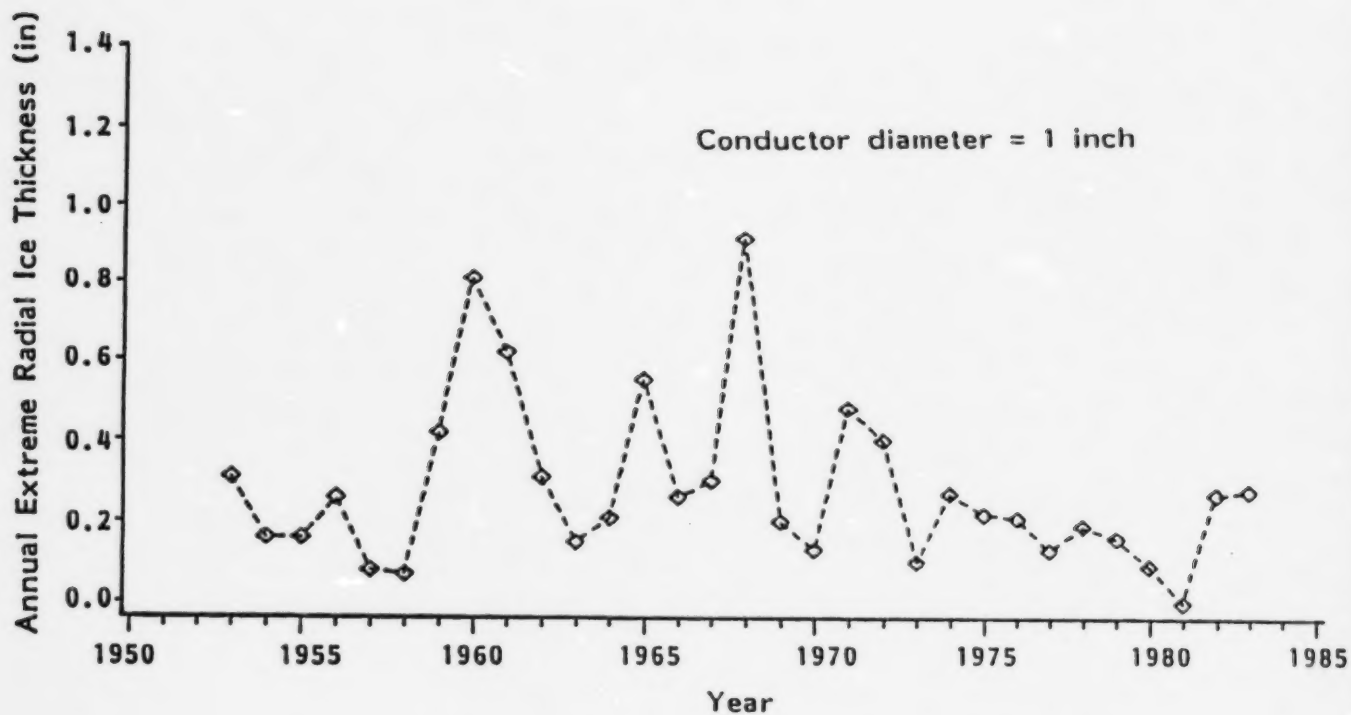


Figure 5. Annual extreme radial ice thickness variation for Toronto International Airport.

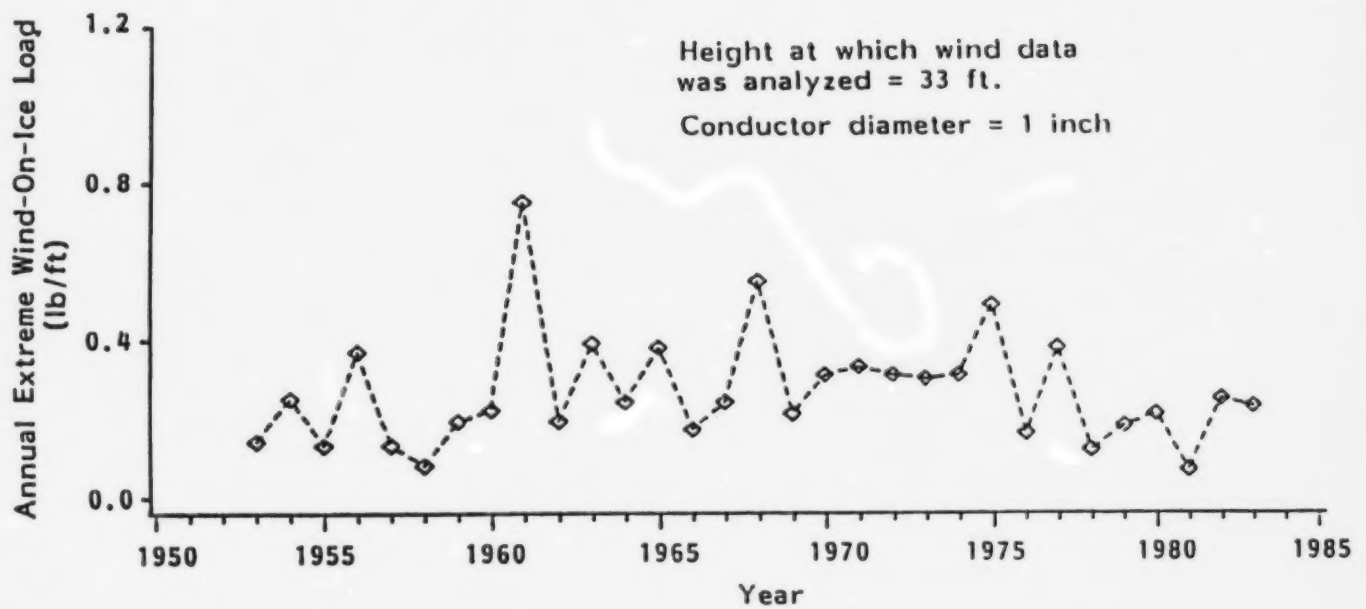


Figure 6. Annual extreme wind-on-ice load variation for Toronto International Airport.

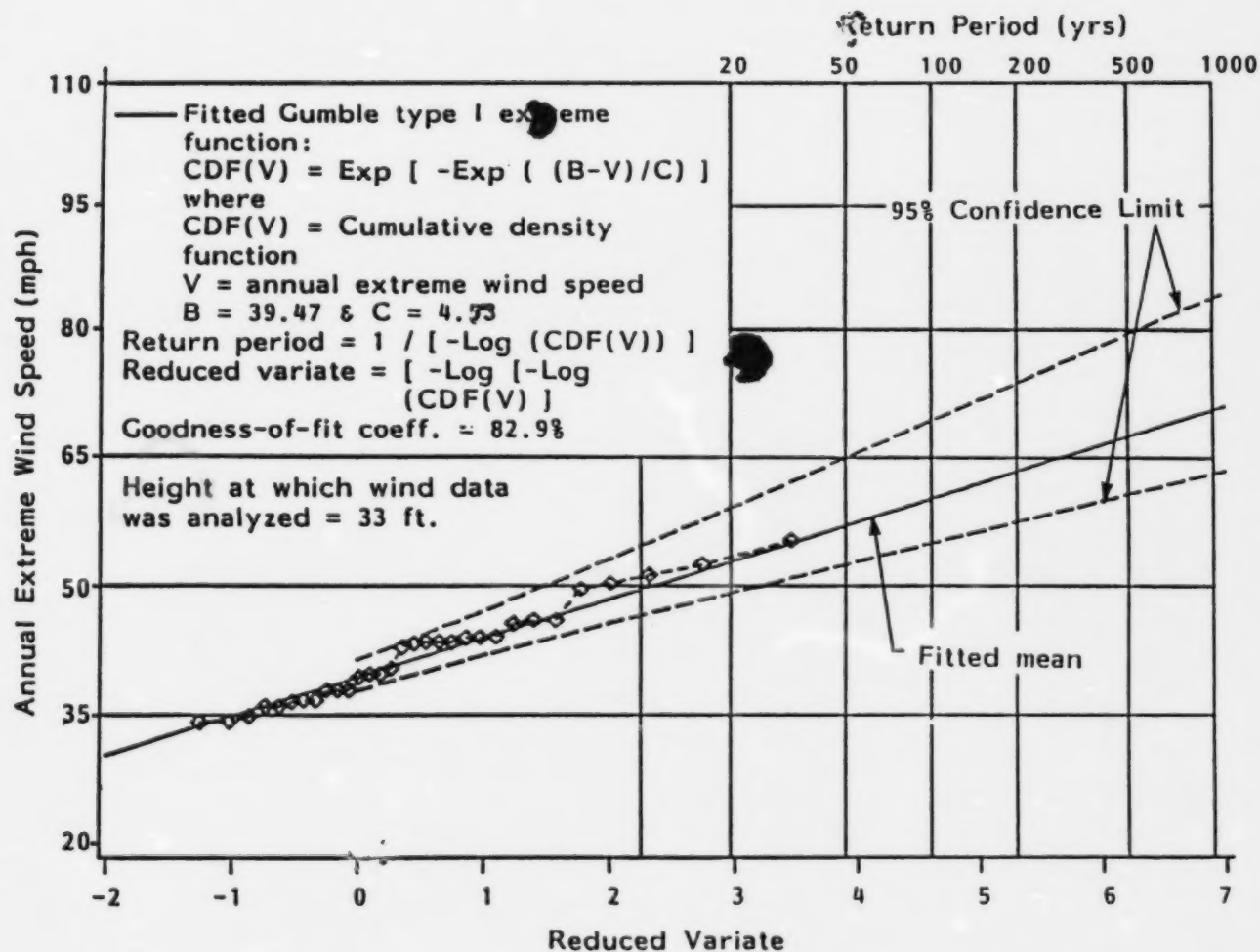


Figure 7. Analysis of annual extreme wind speed data for Toronto International Airport.

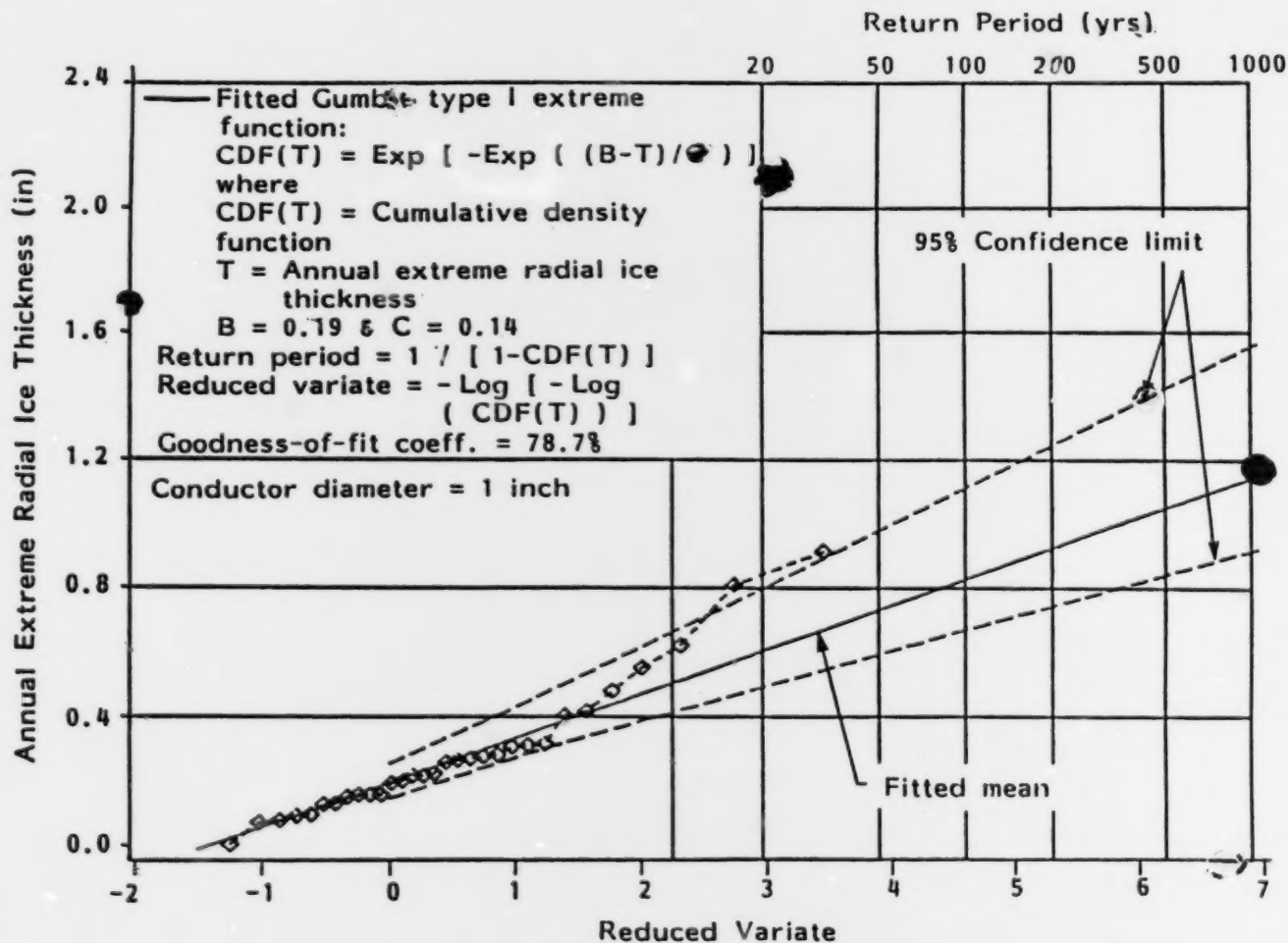


Figure 8. Analysis of annual extreme radial ice thickness for Toronto International Airport.

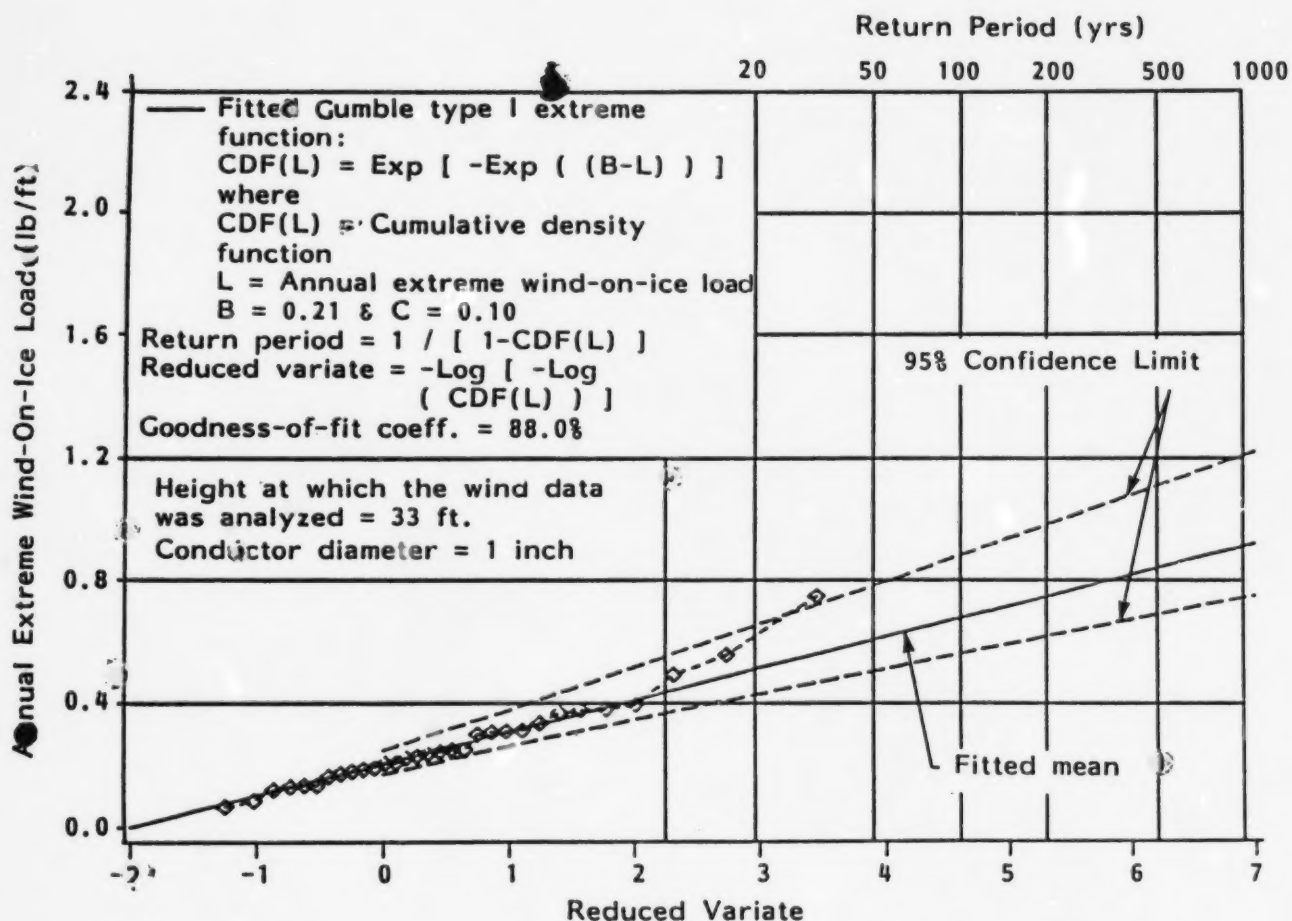


Figure 9. Analysis of annual extreme wind-on-ice load for Toronto International Airport.

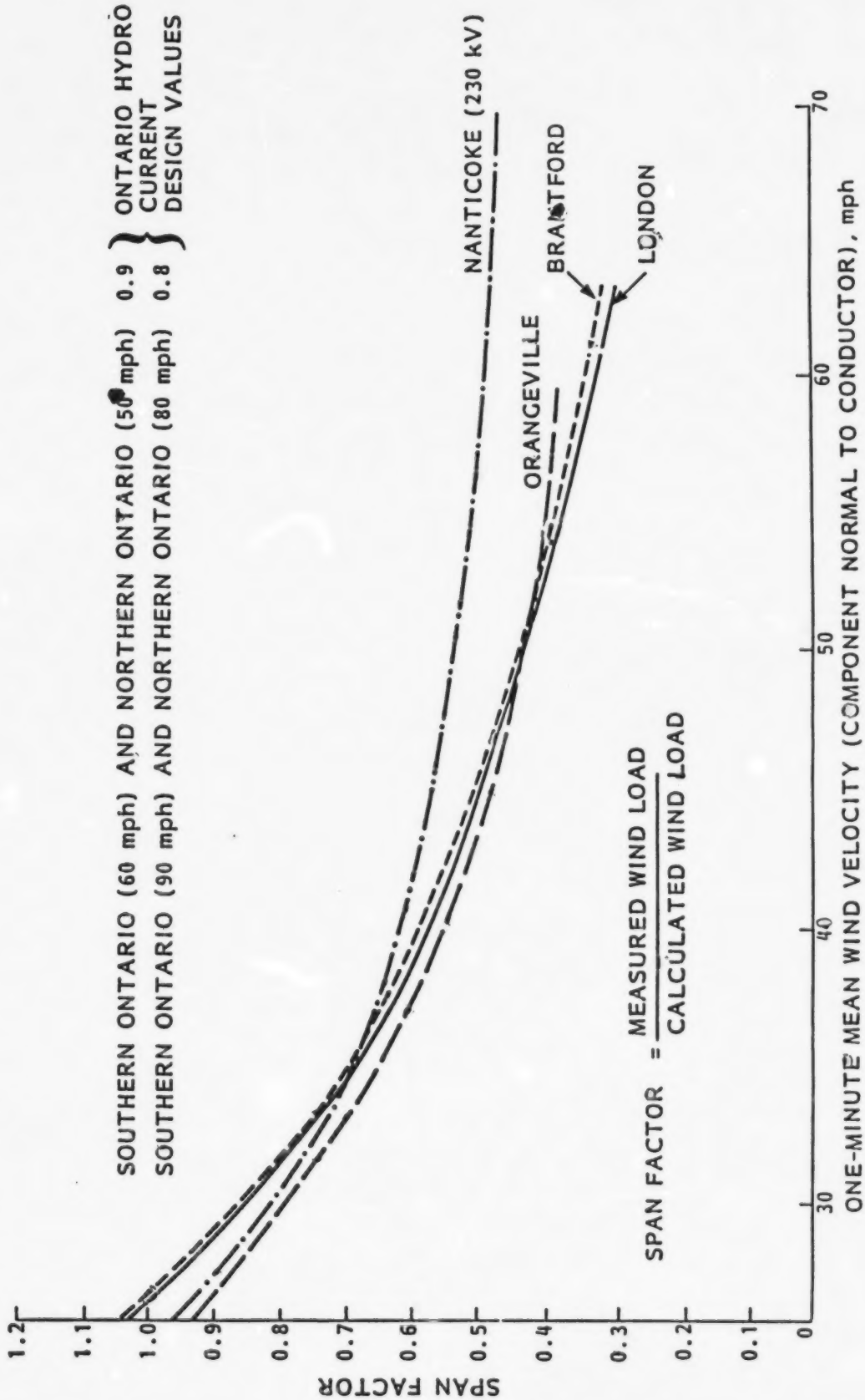


FIGURE 10
 SPAN FACTORS FOR FOUR
 ONTARIO HYDRO TEST SPANS

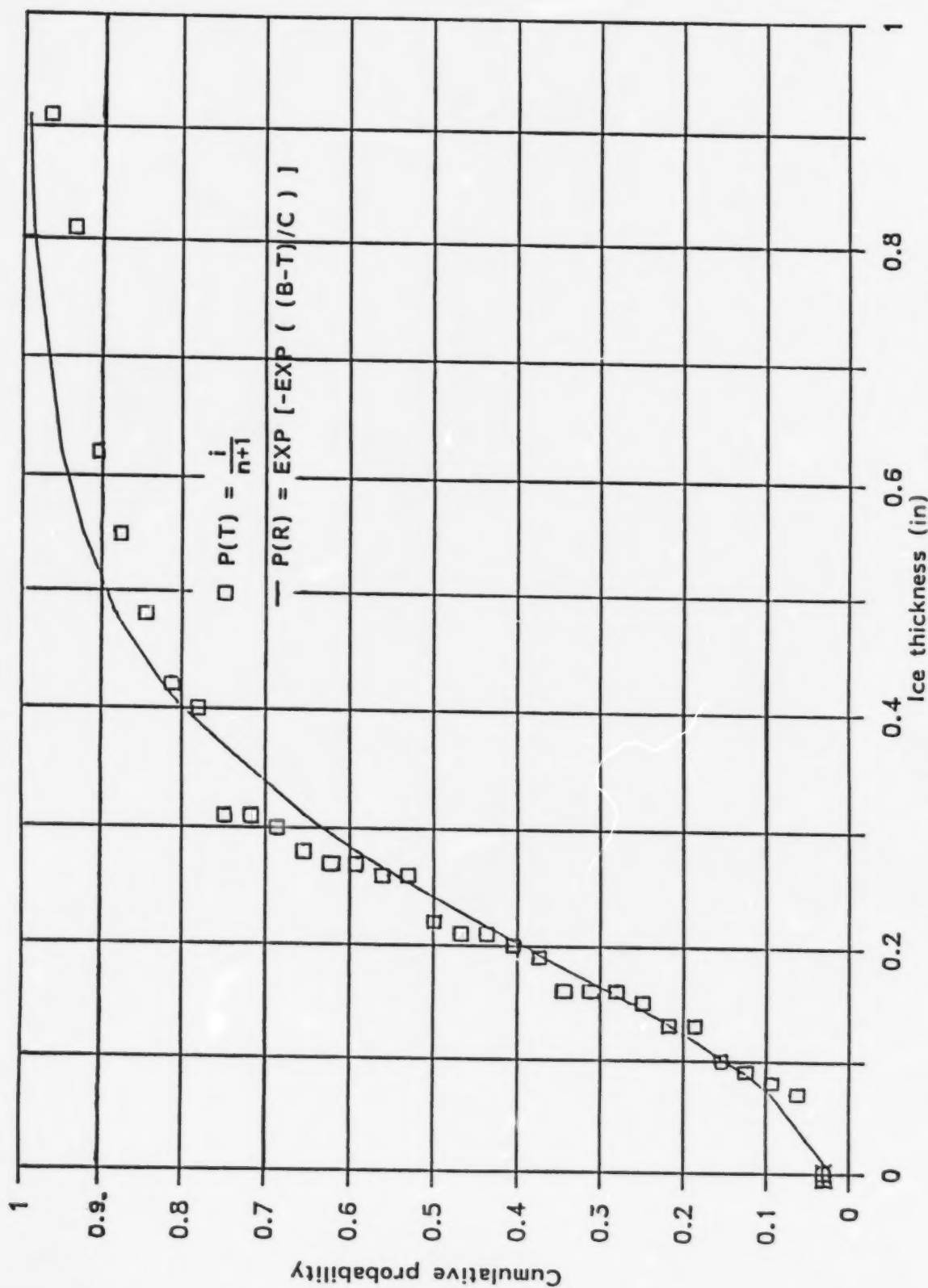


Figure 11-1 Comparison between annual extreme radial ice thickness values and the corresponding Gumbel type I model.